ASD TECHNICAL REPORT 61-424

GUIDE TO INTEGRATED SYSTEM DESIGN FOR MAINTAINABILITY

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NORTHROP CORPORATION
NORAIR DIVISION
HAWTHORNE, CALIFORNIA

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BEHAVIORAL SCIENCES LABORATORY
AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This report covers part of the work performed between April, 1960 and June, 1961 under Contract No. AF 33(616)-7059 "A Guide to Integrated System Design for Maintainability," in support of Project No. 7184, "Human Performance in Advanced Systems," Task No. 71586, "Design Criteria for Ease of Maintenance." The balance of the work is reported in a Technical Note, "Problems and Procedures in Maintainability." The project was administered for the Aerospace Medical Laboratory of the Aeronautical Systems Division by Major Leroy Pigg, Maintenance Design Section, Human Engineering Branch, Behavioral Sciences Laboratory.

The work was greatly aided by the continuous support, advice, and critical comments of Major Pigg and his staff. Many key suggestions and comments were made at a seminar* conducted for the purpose of discussing the study and during interviews and general discussions. For these comments the authors express thanks to: R. M. Belless, Dr. N. Bond, Dr. S. J. Briggs, J. Brower, C. Cleveland, K. R. Colson, Dr. S. Deutsch, E. Engoron, S. Firstman, J. D. Folley, Jr., R. W. Gibson, M. Grodsky, Dr. R. W. Highland, J. Howard, N. Jordan, M. Kamins, A. Kurth, Dr. M. J. Marcus, Major B. McIntosh, Dr. G. L. Murphy, J. Oliver, D. Peterson, Dr. M. J. Rappaport, B. Rucks, A. Shapero, T. Shafer, T. B. Slattery, Dr. A. Swain, E. Ushkow.

The material presented in this report was obtained from the sources listed in the Bibliography. Except for the manner of presentation, very little original data is provided, and the authors are heavily indebted to their sources. However, the manner of presentation often makes it impossible to distinguish source. Therefore, specific credits are given only to acknowledge cases of direct use.

The project was administered at Northrop Corporation, Norair Division, Hawthorne, California, by Dr. J. G. Wells, Supervisor, Human Engineering Branch. Mr. Joel Cooper was responsible for the technical direction. The integration of the material presented was carried out by Mr. Lynn Rigby assisted by Mr. William Spickard. The authors are indebted to Mr. John Kokalj whose technical excellence in the preparation of the illustrative material contributed so greatly to the success of the study.

* For proceedings of seminar see Cooper, J. I., Rigby, L. V., & Spickard, W. A., Proceedings of Shirt Sleeve Seminar on Maintainability, NOR 60-320, August, 1960.

ABSTRACT

This report presents human engineering recommendations and suggestions concerning the design of Air Force weapon systems for ease of maintenance.

The report is divided into three main sections: "Introduction," which discusses the format of the report; "System Decisions for Maintainability," which discusses system design decisions and interactions; and "Detail Design for Maintainability," which presents detailed design recommendations. A Decision Structure Chart provides the system designer with a notation of the critical elements of maintainability and a Topic Index Matrix presents the detail designer with an estimate of the general importance of the interactions of specific design elements.

PUBLICATION REVIEW

Walter F. Grether

WALTER F. GRETHER
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INTRODUCTION

General

Over the past few years, the requirements for highly available weapon and space systems in the military services has risen sharply. This need seems likely to continue, and in fact, become more critical as time goes on. Compounded with this are increased complexities in the systems, demands for extreme accuracy of response, and the imposition of extraordinary environmental constraints, all of which tend to reduce the availability of the system.

The picture is further complicated by the iterative process of design, itself; i.e., system design has been a learning process in which a design configuration is established, produced in some form, tested, redesigned, and reworked. For large production runs the costs of the design process can be amortized without great burden.

By contrast, military systems presently being considered or developed consist, in general, of very limited production quantities. Each will be costly, complicated, and operationally demanding. As a consequence, there is a "right the first time" criterion being imposed on these military systems. This criterion demands that designers have at hand a knowledge of the consequences of each decision that they may make. Since each decision tends to limit the freedom of choice in subsequent decisions, the early decisions are exceedingly critical.

The design process obligates the designer to make numerous decisions in many areas. To facilitate this process, an orderly and useable presentation of information, pertinent to each of these areas, is needed. This guide provides an integrated presentation of information affecting design decisions in the area of maintainability. It is recognized, however, that decisions in the area of maintainability will affect decisions in other areas as well.

Classification of Elements

A classification of elements can be based on the following explanation of maintainability.

> Maintainability is a quality of the combined features and characteristics (equipment design, job aids, and job supports) of a system which facilitate the rapidity, economy, ease, and accuracy with which maintenance operations can be performed, and the system thus kept in or returned to operating condition, by average Air Force personnel, under the environmental conditions in which the system will be maintained.

From this explanation, maintainability elements can be categorized as: *

*Explanations for each of the sub-items can be found on pages 35 through 37.

-Characteristics which facilitate maintenance performance. (Equipment attributes).

-Methods for keeping system in or returning it to an operating condition. (Maintenance methods).

-Methods for determining whether the system is an operating condition. (Test methods).

-Echelons of maintenance in which the system will be returned to an operating condition. (Maintenance levels).

-Steps which are taken in keeping a system in or returning it to an operating condition. (Maintenance actions).

The manner in which these elements are considered and interrelated in the guide is discussed in Section II, System Decisions for Maintainability.

<u>Format of the Guide</u>

The guide has been based on the assumption that there are two general, though not sharply definable, stages of system design. In the first stage, system design, the philosophies and concepts are established. These are used as guidelines for the second stage, detail design. The guide that follows, therefore, is divided into two parallel sections. Section II, System Decisions for Maintainability, provides a method by which the system designer can examine the effects of each decision in the domain of maintainability, while Section III, Detail Design for Maintainability, offers data for detail design once the system decisions have been made.

SECTION II

SYSTEM DECISIONS FOR MAINTAINABILITY

Interactions in the Guide

The system designer is responsible for providing the detail designer with specific requirements for systems maintainability and for integrating these requirements with the system support analyst. To do this, he must be able to delineate maintainability elements and the interactions among them. Additionally, he must consider the interactions between maintainability and support elements. The maintainability elements are detailed below:

Equipment Attributes

- Accessibility
- Coding and Labeling
- Connectors
- Controls
- Displays
- Fasteners
- Size
- Shape
- Standardization
- Test Equipment
- Test Points
- Tools
- Weight

Maintenance Methods

- Adjusting
- Aligning
- Auxiliary Redundancy
- Back up Systems
- Bits and Pieces Maintenance
- Calibration
- Modular Replacement
- No Maintenance
- Parallel Redundancy
- Parallel Working Systems
- Periodic Maintenance
- Periodic Overhaul
- Preventive Maintenance
- Redundancy-Automatic Switching
- Redundancy-Manual Switching
- Remote Ground Switching
- Safety Factors
- Servicing
- Throw Away Maintenance

Test Methods

- Automatic Testing
- Component Testing
- Confidence Testing
- Continuous Check
- Continuous Monitoring-Human
- Continuous Monitoring-Machine
- Crew Stations Check
- Flight Irregularities
- Leave Alone
- Manual Testing
- Marginal Testing
- Periodic Check
- Post-Flight Check
- Pre-Flight Inspection
- Pre-Launch Inspection
- Sequential Degradation Analysis
- Time Scheduled Servicing
- Visual Inspection
- Walk Around Inspection

Maintenance Levels

Depot Level	In-Flight Level
Field Level	Organizational Level

Maintenance Actions

Recognize Malfunctioning Unit	Remove Unit
Isolate Malfunction within Unit	Repair Unit
Adjust Unit	Service Unit

The way in which the Guide considers the interaction between elements is illustrated in Figure 1, "Methods of Treating Interaction between Maintainability Elements." The interactions are referenced by page numbers to the section of the Guide in which they are treated.

Figure 2, "Maintainability Decision Structure," displays the interactions between equipment attributes and maintenance actions. The structure is used as a means of presenting the decision choices available to the system designer. It provides the system designer with the system and support considerations pertinent to each maintenance action. The detail considerations are also referenced for use by the detail designer. The specific details are given in Section III, "Detail Design for Maintainability," and can be found by reference to the TIM Chart, page 157, or the index, pages 149 to 156.

Figure 3, "Relationship between Test and Maintenance Methods," traces the relationship between the methods, indicating the choice of test methods and maintenance methods for ground, manned and unmanned in-flight maintenance. Page references have been made to the section of the Guide in which the interactions and explanations of the methods are given.

The delineation of the techniques is carried out somewhat differently for test and maintenance methods, respectively. Each test method is resolved into a general list of problems and advantages. The maintenance methods are treated in terms of equipment attributes, time factors, logistics, and skill levels, respectively, for each level of maintenance. Using this presentation, the system designer should be able to examine the ramifications of each decision factor and weigh these factors against reliability, logistics, etc., in order to arrive at a design approach for meeting performance requirements. By reference to Section III of this Guide, the detail designer should then be able to convert these decisions into equipment decisions which will satisfy the maintainability requirements for the specific system.

Criteria for Maintenance Levels

Criteria have been selected for each level of maintenance as defined in Air Force Regulation AFR 66-29, 20 November 1960.

(1) Maintainability (Organizational). The capability of an equipment to be returned to an operational status in a specified period of time.

(2) Maintainability (Field). The capability of an equipment to be returned to a serviceable status with specified test and repair equipment within a specified period of time.

(3) Maintainability (Depot). The capability of an equipment to be overhauled and returned to a serviceable condition at a specified percent of unit cost.

In-flight maintenance has also been considered, and is defined as the capability of an equipment to be kept in operational status without endangering flight personnel.

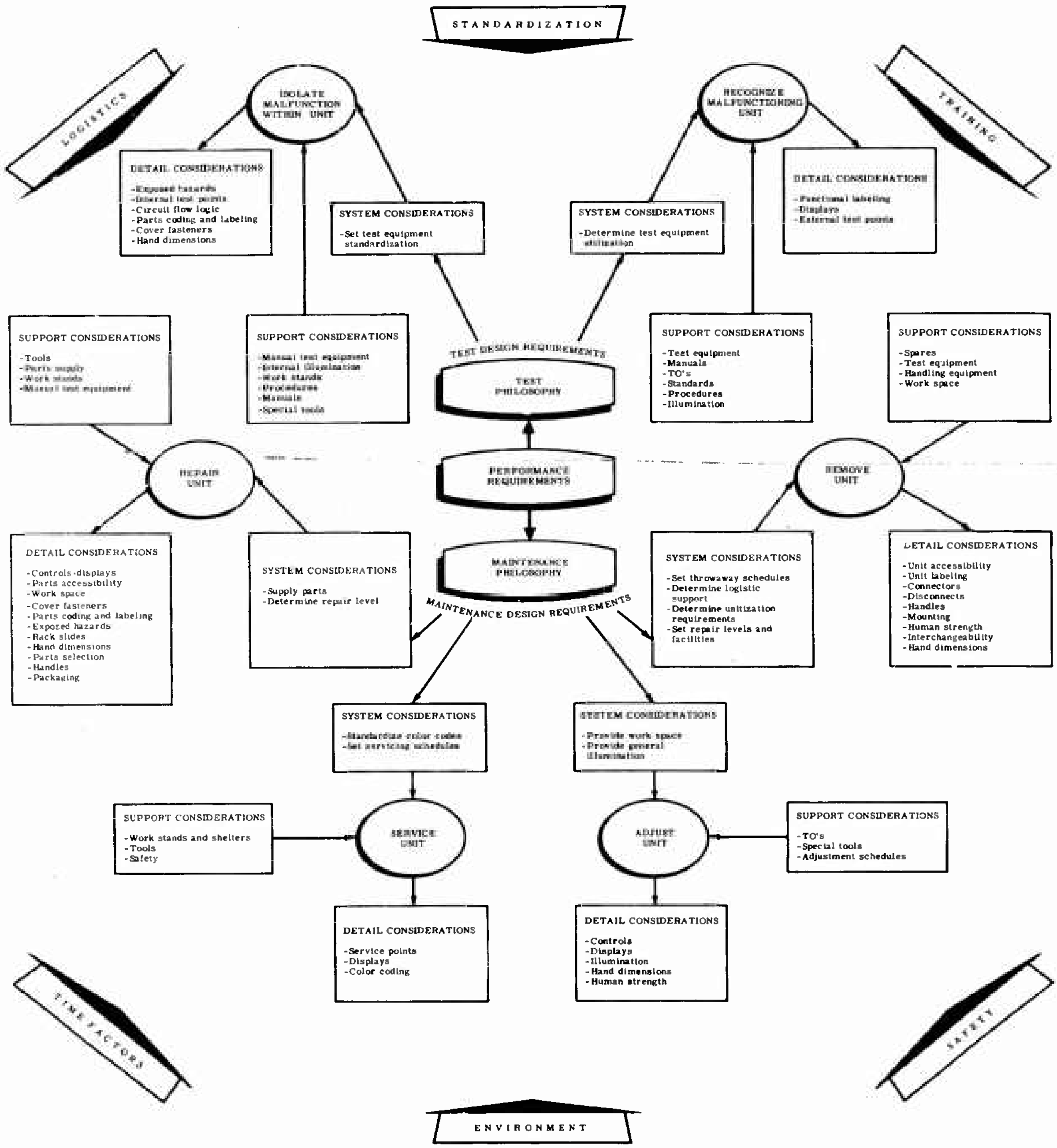
From these definitions the criterion of maintainability for each level of maintenance has been determined as follows:

In-flight - Crew Safety
Organizational - Readiness
Field - Adaptability to Routine
Depot - Accuracy at Acceptable Cost

	MAINTENANCE METHODS	MAINTENANCE ACTIONS	TEST METHODS	MAINTENANCE LEVELS	EQUIPMENT ATTRIBUTES
MAINTENANCE METHODS	See pp. 9-27 Explanation of terms pp. 35-37		See Figure 3	See pp. 9-27	See pp. 9-27
MAINTENANCE ACTIONS		See Figure 2		See pp. 9-27	See Figure 2
TEST METHODS			See pp. 28-31 Explanation of terms pp. 35-37		See Section III
MAINTENANCE LEVELS				See pp. 32-33 Explanation of terms pp. 35-37	See pp. 9-27
EQUIPMENT ATTRIBUTES					See Section III

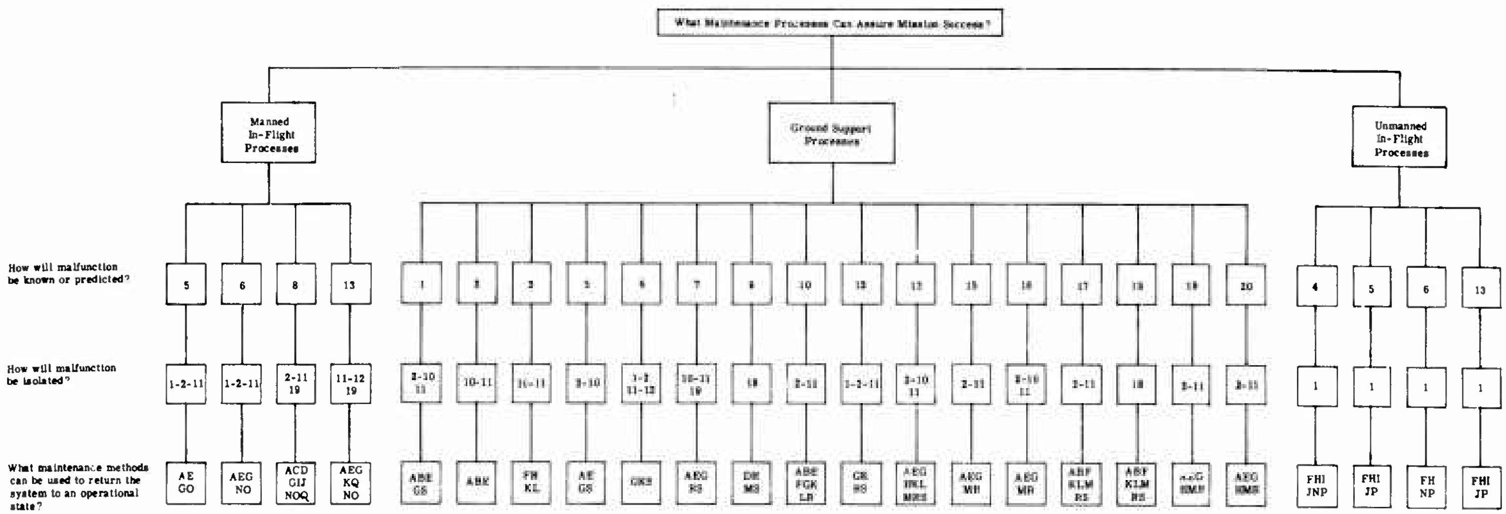
METHOD OF TREATING INTERACTIONS BETWEEN MAINTAINABILITY ELEMENTS

FIGURE I



MAINTAINABILITY DECISION STRUCTURE

FIGURE 2



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RELATIONSHIP BETWEEN TEST AND MAINTENANCE METHODS

FIGURE 3

MODULAR REPLACEMENT

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes				
1. Accessibility	Modules must be so designed as to be quickly and easily removed and replaced Unit must be so designed that replacement does not require removal or disconnect of another module	SAME AS IN-FLIGHT LEVEL	No modular replacement at this level of maintenance Access to signal input and output points must allow for repair of modules without major disassembly or removal of components Internal access must be considered from bench check position of module Components should not be placed so that technician has to rely on feel	No modular replacement at this level of maintenance Final adjustments (if made) should be possible with cover in position All components should be accessible without removal of other components
2. Coding and Labeling	Replacement modules must be labeled, preferably on face of module	SAME AS IN-FLIGHT LEVEL	All components and their positions must be identified	All components and their positions must be identified to detail levels such as pins on plugs, polarity, etc.
3. Connectors	Must be reliable and capable of quick disconnect Equipment should be shut down during maintenance to prevent arcing of connectors Unique keys should be provided for each module group	SAME AS IN-FLIGHT LEVEL	Permanent soldered connections can be used with internal wiring	SAME AS FIELD LEVEL
4. Controls	If adjustments are provided they should be placed on face of module with positive covers to prevent accidental disturbing	SAME AS IN-FLIGHT LEVEL	Internal controls to be adjusted should be accessible without module disturbance	Internal controls must be undisturbed by handling
5. Displays	Should indicate malfunctions to the level of remove-replace	SAME AS IN-FLIGHT LEVEL	Not applicable at this level of maintenance	SAME AS FIELD LEVEL
6. Fasteners	Must be quick and positive	SAME AS IN-FLIGHT LEVEL	Must be positive and undisturbed by handling	SAME AS FIELD LEVEL

MODULAR REPLACEMENT (continued)

	In-Flight	Organizational	Field	Depot
7. Size	Modules must be within size requirement as specified on pp.54-61 Handles must be provided in accordance with requirements on pp.52-53	SAME AS IN-FLIGHT LEVEL	Provisions must be made so that components can be handled Handles should allow the module to be carried conveniently Repair of modules prevents maximum density	SAME AS FIELD LEVEL
8. Shape	Shape of modules must be designed for ease of human handling, (see p.60)	SAME AS IN-FLIGHT LEVEL	Module parts must be of materials and shape which can be handled (see p.60) If not, special handling techniques or tools must be designed and provided	SAME AS FIELD LEVEL
9. Standardization	Modules must be sufficiently uniform for direct interchangeability without adjustment The design for parallel modules will ease replacement and logistics problems Each module should be functionally complete and functionally independent of other modules	SAME AS IN-FLIGHT LEVEL	Standard symbols should be used for identification of components Standard and logical signal flow and circuit groupings should be used in design of modules	SAME AS FIELD LEVEL
10. Test Equipment	Should indicate malfunctions to level of remove-replace Reliabilities should exceed equipment reliabilities by a factor of ten Self check features are required at this level of maintenance Design of special test equipment must conform to Human Engineering requirements (pp.109-117) Malfunction indications must be unambiguous Each test function should indicate the module being tested	Should indicate malfunctions to level of remove-replace Reliabilities must exceed equipment reliabilities by a factor of ten For high degree of readiness self check features should be included Design of special test equipment must conform to Human Engineering requirements (pp.109-117) Malfunction indications must be unambiguous Each test function should indicate the module being tested	General test equipment is most useful at this level Regular routine checks of equipment accuracies are required Final testing of module must be dynamic and include ability to check anticipated system marginal conditions	General test equipment is most useful at this level; however, equipment accuracies should be extremely high Must provide for standards for maintaining equipment accuracies Final testing of module must be dynamic and include ability to check anticipated system marginal conditions Where ATE is used at depot level it must have capability to check at component level

MODULAR REPLACEMENT (continued)

	In-Flight	Organizational	Field	Depot
11. Test Points	Any test points that are used should be on face of panel and in accord with Human Engineering principles (pp.87-93) fforlocation, spacing, identification, etc. Normally not necessary at this level of maintenance unless tester must be checked	SAME AS IN-FLIGHT LEVEL	Must be provided internally for signal input and output by stages Must conform to Human Engineering Requirements (pp.87-93) for location, spacing Indications must be compatible with TO's, Manuals, etc.	Not critical at this level of maintenance unless ATE is used for check Must be provided in circuits where component density will not allow internal accessibility
12. Tools	No tool requirements other than for adjustment (if provided), or where remove-replace fasteners require tools (which should be avoided if possible)	SAME AS IN-FLIGHT LEVEL	General bench tools are sufficient	SAME AS FIELD LEVEL
13. Weight	Weight of modules must be within human capability to handle. See Human Engineering requirements (pp.142-143)	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	N/A
B. Time Factors	Replacement of modules takes time from operating duties Balance of system is usually inoperative during check out and replacement time Replacement time is usually short if modules are properly designed	Balance of system is usually inoperative during check out and replacement time Replacement time is usually short if modules are properly designed	Necessity to keep module small will increase repair time Downtime for balance of system is not affected at this level	Necessity to keep module small will increase repair time Accuracies must be high to preclude system down time at organizational and in flight levels of maintenance. Repair times will be lengthened
C. Logistics	Tool requirements are extremely low Size and weight of added spares may impose a severe logistic requirement Adequate data on time to failure for modules is necessary to logistic planning Extremely careful planning is necessary to ensure mission success and yet to prevent excessive weight	Tool requirements are extremely low Adequate data on time to failure for modules is necessary to logistic planning Adjustment provisions may help overcome problems of tolerance build-ups or non-replaceability of modules but increase demands for personnel, time, etc.	Normal tool requirements are sufficient General test equipment requirements exist Components and subassembly supply are necessary Availability and updating of service manuals are required Supply Group must be able to return modules to organizational or in-flight level as soon as repairs are complete	Repair must be extremely accurate to prevent return of malfunctioning units to operational groups Lack of component supply can cause serious hold up of necessary modules Supply Group must be able to return modules to organizational or in-flight level as soon as repairs are complete

MODULAR REPLACEMENT (continued)

	In-Flight	Organizational	Field	Depot
C. Logistics (Cont.)	Accuracy and reliability of each replacement module must be assured Adjustment provisions may help overcome problems of tolerance build-ups or non-replaceability of modules			
D. Skill Levels	If modules are directly interchangeable without adjustment skill level requirements are very low If test equipment must be maintained skill level requirements may be extremely high Self check features on ATE can reduce skill levels necessary to maintain ATE By providing adjustment capability and raising skill levels slightly, ability to keep module and system functioning may be increased substantially	SAME AS IN-FLIGHT LEVEL	Skill levels can be maintained at an average level by providing logical test and maintenance procedures	Skill level requirements are high

BITS AND PIECES MAINTENANCE

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes				
1. Accessibility	Accessibility is a key factor. Equipment must be so designed as to allow access to all parts. Pull out drawers with sufficient cable length are needed Maximum density is prohibited Components should not have to be removed to reach other components	SAME AS IN-FLIGHT LEVEL	NOT AS CRITICAL HERE	NOT AS CRITICAL HERE
2. Coding and Labeling	All components must be labeled as to be easily identified Labels should be used to identify mounted parts	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
3. Connectors	Connectors of all types can be used as long as the connection is reliable Soldered and fixed connections of all types are permitted and even preferred	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
4. Controls	No special requirements other than good engineering and Human Engineering practices	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
5. Displays	No special requirements other than good engineering and Human Engineering practices	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
6. Fasteners	Normal well engineered fasteners not requiring special tools should be used	SAME AS IN-FLIGHT	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
7. Size	Provisions must be made so that components can be handled conveniently Handles should allow the units to be carried conveniently	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL

BITS AND PIECES MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
8. Shape	Shape must be in accordance with Human Engineering requirements (pp. 43 & 82)	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
9. Standardization	Use standard symbols for identification of components The standard and logical signal flow and circuit groupings should be used in design of units	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
10. Test Equipment	Standard test equipment is usable Semi-automatic equipment can be used to locate malfunctioning unit Routine checks of test equipment accuracies must be made	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	Test equipment at this level must be extremely accurate. General bench equipment with close tolerance is usable
11. Test Points	Must be provided internally for signal input and output by stages Must conform to Human Engineering requirements for location, spacing, identification etc. (see pp. 87-93) Indications must be compatible with TO's, Manuals, etc. Test points for key functions should be on front of panel	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	Not critical at this level of maintenance
12. Tools	Complete general tools and any special tools must be provided	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
13. Weight	Weight is low because no special requirements exist Service manual weight is added	Weight is low because no special requirements exist	Must be within human capability to handle (see pp. 142-143) or handling equipment must be supplied	SAME AS FIELD LEVEL

BITS AND PIECES MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
B. Time Factors	Fault localization time is extremely high. To build automatic localization to this level of maintenance is prohibitive Time to repair is extremely high. Use of equipment is lost during this time in addition to crew time loss for maintenance	Fault localization time is extremely high. To build automatic localization to this level of maintenance is prohibitive Time to repair is extremely high. Use of equipment is lost during this time	Fault localization time at this level may be lower than in modular equipment because package size and configuration is less constrained allowing greater freedom in the placement and use of test points for accessibility, etc. Time to repair will probably be shortened since components and access can be handled more advantageously	SAME AS FIELD LEVEL
C. Logistics	Component stock must be programmed Service manuals and job aids must be supplied	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
D. Skill Levels	Skill level requirements are high	SAME AS IN-FLIGHT LEVEL	Skill levels normally available at this level of maintenance are adequate	SAME AS FIELD LEVEL

MAINTENANCE BY REDUNDANCY - AUTOMATIC SWITCHING

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes 1. Accessibility	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	Access to signal input and output points must allow for repair of units without major disassembly or removal of components	Components should be accessible without removal of other components
2. Coding and Labeling	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	All components and their positions must be identified	SAME AS FIELD LEVEL
3. Connectors	Connectors of all types can be used as long as the connection is reliable Soldered and fixed connectors of all types are permitted and even preferred	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
4. Controls	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
5. Displays	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
6. Fasteners	No specific requirements at this level of maintenance unless switching circuitry must be maintained	SAME AS IN-FLIGHT LEVEL	Normal well engineered fasteners can be used	SAME AS FIELD LEVEL
7. Size	Size at this level is limited only by equipment requirements	SAME AS IN-FLIGHT LEVEL	Size must be within human capability to handle or external cranes, dollies, etc. must be supplied (see pp. 94-99)	SAME AS FIELD LEVEL
8. Shape	Shape at this level is limited only by equipment requirements	SAME AS IN-FLIGHT LEVEL	Shape must be within human capability to handle or external cranes, dollies, etc. must be supplied (see pp. 94-99)	SAME AS FIELD LEVEL
9. Standardization	No specific requirement at this level of maintenance	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL

MAINTENANCE BY REDUNDANCY - AUTOMATIC SWITCHING (continued)

	In-Flight	Organizational	Field	Depot
10. Test Equipment	Not applicable at this level of maintenance since the machine is allowed to perform the operation and determine the equipment state	SAME AS IN-FLIGHT LEVEL	General test equipment needed for maintenance at this level	Test equipment with extreme accuracy is required
11. Test Points	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	Must be provided internally for signal input and output by stages Must conform to Human Engineering requirements for location, spacing, identification, etc. (see pp. 87-93)	Not critical at this level of maintenance
12. Tools	Not applicable at this level of maintenance	SAME AS IN-FLIGHT LEVEL	General bench tools are needed	SAME AS FIELD LEVEL
13. Weight	Redundant circuitry plus malfunction indicating equipment will probably add considerable weight	Not critical at this level of maintenance	Weight of units must be within human handling capability or external cranes, dollies, etc. must be supplied (see pp. 94-99)	SAME AS FIELD LEVEL
B. Time Factors	Theoretically, no lost time occurs. Equipment should operate 100 percent of time No time lost from crew duties System is highly responsive if designed properly	Theoretically, no lost time occurs. Equipment should operate 100 percent of time System is highly responsive if designed properly	Time to repair may be extremely high due to complexity of circuitry necessary to accomplish function	SAME AS FIELD LEVEL
C. Logistics	Not applicable as equipment supplies its own spares	SAME AS IN-FLIGHT LEVEL	The capability to return unit to serviceable condition within reasonable time may be very critical in operational and in-flight logistic considerations	SAME AS FIELD LEVEL
D. Skill Level	Skill is not needed at this level of maintenance provided the equipment is operating properly If equipment malfunctions no repair is possible because parts and test equipment are lacking	Skill is not needed at this level of maintenance provided the equipment is operating properly Malfunctioning equipment should be maintained at field or depot level	Complexity of circuitry will demand extraordinarily high skill levels	SAME AS FIELD LEVEL

MAINTENANCE BY REDUNDANCY - MANUAL SWITCHING

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes				
1. Accessibility	Not applicable at this level of maintenance Access to switching circuitry itself may be necessary depending on its reliability	SAME AS IN-FLIGHT LEVEL	No switching at this level of maintenance Access to signal input and output points must allow for repair of units without major disassembly or removal of components	No switching at this level of maintenance All components should be accessible without without removal of other components
2. Coding and Labeling	Coding is important only in display-switch arrangement and compatibility	SAME AS IN-FLIGHT LEVEL	All components and their positions must be identified	SAME AS FIELD LEVEL
3. Connectors	Connectors of all types can be used as long as the connection is reliable Soldered and fixed connections of all types are permitted and even preferred A requirement may exist for quick disconnects for switching circuitry	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS FIELD LEVEL
4. Controls	Sufficient space must be allowed for switches and due consideration given to environmental constraints	SAME AS IN-FLIGHT LEVEL	Not critical at this level of maintenance	SAME AS FIELD LEVEL
5. Displays	Displays must be unequivocal and compatible with switches according to Human Engineering principles Audio as well as visual displays should be provided to alert the operator or maintenance man to the necessity for switching	SAME AS IN-FLIGHT LEVEL	Not critical at this level of maintenance	SAME AS FIELD LEVEL
6. Fasteners	Not critical at this level unless it is necessary to maintain switching circuitry	SAME AS IN-FLIGHT LEVEL	Normal fastener requirements at this level of maintenance	SAME AS FIELD LEVEL

MAINTENANCE BY REDUNDANCY - MANUAL SWITCHING (continued)

	In-Flight	Organizational	Field	Depot
7. Size	Size at this level is limited only by the human capability to reach switches (see pp.47-50))	SAME AS IN-FLIGHT LEVEL	Size must be within human capability to handle (see p.60) or external cranes, dollies, etc. must be supplied (See pp.94-99)	SAME AS FIELD LEVEL
8. Shape	SAME AS SIZE, ABOVE	SAME AS SIZE, ABOVE	SAME AS SIZE, ABOVE	SAME AS SIZE, ABOVE
9. Standardization	Not critical at this level of maintenance, Switch direction of movement must conform to AF standards	SAME AS IN-FLIGHT LEVEL	Not critical at this level of maintenance	SAME AS FIELD LEVEL
10. Test Equipment	Displays should unambiguously indicate malfunction With proper display-switch compatibility there should be no requirements for test equipment other than malfunction indicator itself A requirement may exist for general test equipment or a method of isolation within the indicator if switching circuitry is unreliable	SAME AS IN-FLIGHT LEVEL	General test equipment needed for maintenance at this level	SAME AS FIELD LEVEL
11. Test Points	Not critical at this level of maintenance unless isolation of switching malfunction is accomplished through general testing. Then test points should be on front panel of unit and in accordance with Human Engineering principles (pp.87-93)	SAME AS IN-FLIGHT LEVEL	Must be provided internally for signal input and output by stages Must conform to Human Engineering requirements (pp.87-93)	Not critical at this level of maintenance
12. Tools	Not critical at this level of maintenance unless repair of switching circuitry is contemplated	SAME AS IN-FLIGHT LEVEL	General bench tools are needed	SAME AS FIELD LEVEL
13. Weight	Redundant circuitry plus malfunction indicating equipment will probably add considerable weight	Not critical at this level of maintenance	Weight of units must be within human capability to handle (see p.60) or external cranes, dollies, etc. must be supplied (pp.94-99)	SAME AS FIELD LEVEL

MAINTENANCE BY REDUNDANCY - MANUAL SWITCHING (continued)

	In-Flight	Organization	Field	Depot
B. Time Factors	Time to accomplish switching will be low Time to recognize malfunction should be very low with proper visual indication	SAME AS IN-FLIGHT LEVEL	Time to repair may be very high due to complexity of circuitry that is necessary to accomplish recognition and switching	SAME AS FIELD LEVEL
C. Logistics	Not applicable as equipment contains its own spares	SAME AS IN-FLIGHT LEVEL	The capability to return unit to serviceable condition at this level can be very critical in organizational and in-flight logistic considerations	SAME AS FIELD LEVEL
D. Skill Levels	Low skill level requirements at this level	SAME AS IN-FLIGHT LEVEL	Complexity of circuitry may lead to extraordinarily high skill demands in the maintenance of the redundant circuitry itself	SAME AS FIELD LEVEL

PREVENTIVE MAINTENANCE

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes				
1. Accessibility	NOT PRACTICAL AT THIS LEVEL OF MAINTENANCE	All servicing points (lubrication, adjustment, etc.) should be readily accessible without disassembly of equipment All remove-replace units should be readily accessible without disturbance to other units	All scheduled replacement items should be plug in type and accessible for removal when cover panel removed All service points should be readily accessible without disassembly of equipment	Although preventive maintenance will be done at depot level, no specific design requirements exist. Scheduled replacement will be accomplished here on any item and in any manner which is practical
2. Coding and Labeling	SAME AS ABOVE	All servicing points should be clearly and distinctively labeled All servicing points should be identified by standard color codes All replacement modules or units should be identified by standard color codes	All servicing points should be clearly and distinctively labeled All servicing points should be identified by standard color codes All plug in units scheduled for replacement should be identified by standard color codes	SAME AS ABOVE
3. Connectors	SAME AS ABOVE	Must be reliable and capable of quick-disconnect	All replacement units should be plug-in type	SAME AS ABOVE
4. Controls	SAME AS ABOVE	All adjustments should be on face or easily accessible with standard tools Covers or locks should be provided for adjusting knobs or screws to prevent inadvertent handling	Internal controls to be adjusted should be accessible without disturbance to unit	SAME AS ABOVE
5. Displays	SAME AS ABOVE	Displays should be located on face of equipment and accessible in normal position	No specific requirements at this level of maintenance	SAME AS ABOVE
6. Fasteners	SAME AS ABOVE	Must be quick and positive	Must be positive and undisturbed by handling	SAME AS ABOVE

PREVENTIVE MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
7. Size	NOT PRACTICAL AT THIS LEVEL OF MAINTENANCE	Replaceable units must be within requirements as specified by Human Engineering Design Guides (see pp.54-61) Handles, U bolts, or eye bolts for moving or handling must be provided External aids must be provided where size exceeds human handling capability	SAME AS ORGANIZATIONAL LEVEL	Although preventive maintenance will be done at depot level, no specific design requirements exist. Scheduled replacement will be accomplished here on any item and in any manner which is practical
8. Shape	SAME AS ABOVE	Replaceable units must be within requirements as specified by Human Engineering Design Guides (see pp.54-61) External aids must be provided where shape exceeds human handling capability	SAME AS ORGANIZATIONAL LEVEL	SAME AS ABOVE
9. Standardization	SAME AS ABOVE	Units must be sufficiently uniform for direct interchangeability without adjustment Service fittings and lubrication requirements should be standardized as much as possible	Plug-in units must be sufficiently uniform for direct interchangeability without adjustment Standard and logical flow groupings should be used in design of modules Standard plugs should be used for each basic unit and keys provided for non-interchangeable units	SAME AS ABOVE
10. Test Equipment	SAME AS ABOVE	For scheduled maintenance no test equipment requirements exist For predicted wearout periodic check, general test equipment is usually required In hazardous, or toxic areas continuous monitoring instruments are needed Marginal tests also will be used	Standard bench instruments which are used for general repair at this level will also serve for preventive maintenance	SAME AS ABOVE

PREVENTIVE MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
11. Test Points	**NOT PRACTICAL AT THIS LEVEL OF MAINTENANCE**	Output points should be on front panel of unit in accordance with Human Engineering requirements for location, spacing, identification, etc. (see pp.87-93)	Input and output points should be on accessible part of plug-in unit in accordance with Human Engineering requirements (see pp.87-93)	Although preventive maintenance will be done at depot level, no specific design requirements exist. Scheduled replacement will be accomplished here on any item and in any manner which is practical
12. Tools	SAME AS ABOVE	Standard tools are required	Standard bench tools are required	SAME AS ABOVE
13. Weight	SAME AS ABOVE	Replaceable units must be within requirements as specified by Human Engineering Design Guides (see p.60) Handles, U bolts, or eye bolts for moving and handling must be provided External aids must be supplied where weight exceeds human handling capability	SAME AS ORGANIZATIONAL LEVEL	SAME AS ABOVE
B. Time Factors	SAME AS ABOVE	Maintenance can be scheduled during normal system downtime Time lost in malfunction diagnosis may be reduced by prediction of when units should be repaired More total maintenance time may be required because of replacement before failure but time losses at critical times will be reduced Maintenance man's time can be used more efficiently since preventive maintenance can be done in off hours	SAME AS ORGANIZATIONAL LEVEL	SAME AS ABOVE
C. Logistics	SAME AS ABOVE	Scheduling should be simpler because rate and time of use of units or components can be predicted in advance and flow can be methodically programmed	SAME AS ORGANIZATIONAL LEVEL	SAME AS ABOVE
D. Skill Levels	SAME AS ABOVE	Skill levels are generally low Prediction of when to replace on gradual degradation may require somewhat higher skill levels	SAME AS ORGANIZATIONAL LEVEL	SAME AS ABOVE

NO MAINTENANCE

	In-Flight Maintenance Criterion - Crew Safety	Organizational Maintenance Criterion - Readiness	Field Maintenance Criterion - Adaptability to Routine	Depot Maintenance Criterion - Accuracy at Acceptable Cost
A. Equipment Attributes				
1. Accessibility	No specific requirements at this level of maintenance Maximum density is allowable	SAME AS IN-FLIGHT LEVEL	Maintenance must be done at this level Access to signal input and output points should be possible without major disassembly or removal of components Components should not be placed so that technician has to rely on feel	Maintenance must be done at this level Components should be accessible without removal of other components Final adjustment (if made) should be possible with covers in position
2. Coding and Labeling	No specific requirements at this level of maintenance	SAME AS IN-FLIGHT LEVEL	All components and their positions must be identified	All components and their positions must be identified to detail levels such as pins on plugs, polarity, etc.
3. Connectors	Connectors of all types can be used as long as they are reliable Soldered and fixed connections of all types are permitted and even preferred	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
4. Controls	If adjustments are provided they should be placed on face of unit with positive locks or covers to prevent accidentally disturbing	SAME AS IN-FLIGHT LEVEL	Internal controls to be adjusted should be accessible without module disturbance	Internal controls must be undisturbed by handling
5. Displays	N/A	N/A	N/A	N/A
6. Fasteners	Must be positive	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL	SAME AS IN-FLIGHT LEVEL
7. Size	No specific requirements at this level of maintenance other than those imposed by equipment requirements	SAME AS IN-FLIGHT LEVEL	Size must be within human capability to handle or external cranes, dollies, etc. must be supplied (see pp.94-99)	SAME AS FIELD LEVEL
8. Shape	No specific requirements at this level of maintenance other than those imposed by equipment requirements	SAME AS IN-FLIGHT LEVEL	Shape must be within human capability to handle or external cranes, dollies, etc. must be supplied. (See pp.94-99)	SAME AS FIELD LEVEL

NO MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
9. Standardization	No specific requirements at this level of maintenance other than those imposed by equipment requirements	SAME AS IN-FLIGHT LEVEL	Use standard symbols for identification of components Use standard and logical signal flow and circuit groupings	SAME AS FIELD LEVEL
10. Test Equipment	Not applicable at this level of maintenance	SAME AS IN-FLIGHT LEVEL	General test equipment is most useful at this level Regular routine checks of equipment accuracies required Final testing of unit must be dynamic and include ability to check anticipated marginal conditions	General test equipment is most useful at this level. Accuracies must be extremely high Must provide standards for maintaining test equipment accuracies Final test of unit must be dynamic and include ability to check anticipated system marginal conditions
11. Test Points	No specific requirements at this level of maintenance unless adjustments are to be made If adjustments are to be made test equipment must be available and test points must be in accord with Human Engineering requirements	SAME AS IN-FLIGHT LEVEL	Must be provided internally for signal input and output by stages Must conform to Human Engineering requirements for location, spacing, identification, etc. (see pp.87-93) Indications must comply with TO's, manuals, etc.	Not critical at this level of maintenance
12. Tools	Not applicable at this level of maintenance	SAME AS IN-FLIGHT LEVEL	General bench tools are needed	SAME AS FIELD LEVEL
13. Weight	Although no weight impositions result from maintenance considerations, weight can be considerable reduced because of tool and equipment reductions	Not critical at this level of maintenance	Must be within human capability to handle or handling equipment must be supplied	SAME AS FIELD LEVEL
B. Time Factors	Maintenance time is not critical unless adjustment is contemplated Equipment shut down time for maintenance is not applicable	SAME AS IN-FLIGHT LEVEL	Nature of equipment design for "No Maintenance" will make repair more difficult and time consuming	Accuracies must be high to preclude system down-time at organizational and in-flight levels of maintenance. Repair times will be lengthened Dynamic testing should be used to prohibit return of units that will fail in interaction in the system

NO MAINTENANCE (continued)

	In-Flight	Organizational	Field	Depot
C. Logistics	Component supply and tools necessary Test equipment is not applicable unless adjustment is contemplated	**SAME AS IN-FLIGHT LEVEL**	Component stock must be programmed Service manuals and job aids must be supplied	**SAME AS FIELD LEVEL**
D. Skill Levels	Maintenance skills are not applicable unless adjustment is contemplated. Operator skills can normally accomplish this	**SAME AS IN-FLIGHT LEVEL**	High skill level required due to nature of decision	Extremely high skill levels are required to prohibit return of improperly repaired units to organizational or in-flight levels

ADJUSTING

Problems

- Task is almost impossible for a machine to accomplish
- Process is usually slow and tedious
- Errors of display reading and over-adjustment can occur
- Unknowledgeable manipulation can cause equipment malfunctions

Advantages

- Maintenance or replacement necessities may be reduced by the returning of out-of tolerance elements to an in-tolerance state
- An indication of system degradation can be obtained by having skilled personnel observe display response to control manipulation
- Some necessity for close tolerance components can be reduced

SERVICE

Problems

- Service points must be accessible and thus constraints are placed on structural design
- Fuels are usually volatile, toxic, etc., thus requiring special provisions, handling methods and equipment to reduce hazards to personnel
- The hazards of fuels usually demand that fueling be done outdoors regardless of temperature or climatic conditions
- Many servicing items are severely bothered by contaminants, and thus require extreme cleanliness
- Since many servicing items are in themselves contaminants, great care must be exercised in preventing spill and accomplishing clean up

Advantages

- A means is provided for replenishing extended items
- Protection is provided against wearout failures because of friction, etc.

AUTOMATIC TESTING

Problems

-Distinction cannot be made between critical and non-critical malfunctions

-Deciding which tests should be made is a complex task

-The level of removal to which the tester applies, must be fairly high or the automatic equipment becomes extremely complex

-Complexity of tester makes high reliability difficult

-Unless self-analyzing, the decision as to whether the prime or test equipment is malfunctioning is exceedingly difficult

-Skill levels necessary to maintain tester are extremely high

-In short duration tests, hookup of equipment may consume more time than overall manual testing

-Unexpected occurrences cannot be handled

-Performance of all of the exact tests performed manually is impossible

-All tests needed are difficult to anticipate

-If test equipment is not operational when delivered (which is too often the case), long term "debugging" may be necessary

-Complete tests are ruled out because of complexity

-If test equipment malfunctions, alternate methods are not usually available

Advantages

-Testing is extremely rapid

-Extremely accurate data can be provided and prime equipment tested within very close tolerances

-Essentially, tests can be repeated exactly

-Cost savings can be shown with high utilization

-Skill demands may possibly be reduced

-Large amounts of test data may be stored for long periods

-Tests can be performed in remote locations while equipment is unattended

-Testing can be against standards rather than judgements

CONTINUOUS MONITORING - AUTOMATIC

Problems

- Component life is reduced because of test operating time
- Machine is expensive to design, build, and to operate
- Lead times to design and build can be extensive
- Monitoring equipment employed in hazardous areas can be difficult and dangerous to repair
- Maintenance of monitor demands high skill levels
- Monitoring capability is completely lost during monitor failure
- Machine monitoring is generally not useful at field and depot levels of maintenance

Advantages

- Programming allows prediction of component or system failure before occurrence
- Instantaneous and continuous picture of system state is given
- Reliability data can be provided by programming
- In areas where components might deteriorate as a result of being idle (hydraulic seals, etc.) the operation of a continuous monitor is extremely useful
- Machine monitoring is essential in hazardous areas where toxic materials, high pressures, possible explosions, and temperature controls might exist
- Analyzer features may be incorporated in the monitor, but will usually prevent its use as a monitor while being used as an analyzer
- Low skill levels are required for operation
- Method works well for remote locations

CONTINUOUS MONITOR - HUMAN

Problems

- Man is a notoriously poor monitor
- If no events occur over a reasonably long period of time the human is likely not to see events that do occur
- His ability to monitor more than one output is limited

Advantages

- Events which have not been programmed are liked to be recognized
- Man can make a decision, regardless of its value, based on ambiguous information
- Signals can be distinguished by man in high noise environments
- Man can reprogram with great flexibility
- He can perform while overloaded but efficiency may go down

COMPONENT TESTING

Problems

- Testing time is long
- Response rates and element interaction are not indicated
- Method is poor as a prime test technique because of time, skill and equipment requirements
- True condition of system may not be indicated when summed in system, as tolerance build-ups can lead to out of spec conditions within spec components
- High skill levels are usually demanded

Advantages

- Testing isolates the part to be replaced to the cheapest level
- Malfunctions can be determined in passive elements
- Component testing is a good supplement to system tests
- Can add to reliability of the repaired item

MANUAL TESTING

- A long time is required for testing as well as for training
- High skill levels are required
- Job information support is required
- Testing is subject to inaccuracies of the human operator

- Test equipment does not have to be specially designed
- Equipment is standard and therefore can be used in other systems
- The test logic is flexible enough to be changed easily
- The test level, e.g., system, subsystem, component, etc., is flexible
- Distinction can be made between critical and non-critical failures
- Little lag time occurs in producing or supplying necessary test equipment

CONFIDENCE TESTING

Problems	Advantages
-Method is limited to quick selective tests which provide probability of system readiness	-Extremely quick appraisal of system readiness is provided without interfering with reaction time
-Procedure is essentially designed as a malfunction recognition rather than a malfunction diagnostic device	-A reasonable estimate of the probability of mission success can be provided
-The speed of test can usually be increased only by reducing the number of tests made	

LEAVE ALONE

-The system condition is unknown	-"Bugs" are not introduced by checking and maintenance processes
-High reliability is demanded	-Method is extremely economical
-Degradation can occur in some areas as a result of system inactivity	-No logistic considerations are necessary below the complete system level
-If failure does occur on use, it is likely to be catastrophic	-No requirements exist for test equipment or skill levels

MARGINAL TESTING

-Strains are imposed that can cause system degradation	-Reliable data is given on system performance under hostile and possibly operational conditions
-Programming is extremely difficult in systems composed of many different types of circuits	-Marginal testing is especially useful where system is composed of essentially identical circuits since programming is easy and results are readily interpreted
-Reliability of equipment is difficult to predict when operations are conducted under hostile conditions	

PRE-FLIGHT INSPECTION

Problems	Advantages
-Checking consumes critical readiness time	-Assurance checks of critical system elements can be made
-Time pressures may cause critical checks to be waived	-Aircraft commander's confidence is increased
	-Systems are checked by personnel who know the operational eccentricities of the equipment
	-Military requirements are met

POST-FLIGHT INSPECTION

Problems	Advantages
-Crew members are usually anxious to depart and tend to gloss over less serious malfunctions	-Data is obtained on incipient malfunctions for correction
-Malfunctions which occur with on-board power may not show up under ground power	-A permanent record is provided of all malfunctions encountered (Form 1)
-Intermittent malfunctions may not show up within a reasonable time and consequently be passed by ground crews	
-Communication between air and ground crews may not indicate clearly what is malfunctioning and/or in what manner	

WALK-AROUND INSPECTION

Problems	Advantages
-Determination of what must be visually inspected is not always clearly spelled out	-This inspection reveals incipient malfunctions that cannot be checked conveniently by any other means, e.g., cracks, leaks, abuse, etc.
-Method handles only incipient malfunctions that are visible within the narrow range of human perception	-Crew protective equipment can be checked for cleanliness, leaks, etc.
-Inclemental weather may cause undue haste in checking	-The freedom of mechanical moving parts can be observed
	-Personnel can determine whether safety lock pins have been removed or are in place

IN-FLIGHT MAINTENANCE

Problems	Advantages
-Other crew duties seriously limit time available for maintenance	-Crew safety is increased
-Weight and size seriously limit the test equipment, tools and replacement parts that can be carried	-Maintenance possibilities provide against unforseen events
-Specificity of crew operational training limits crew maintenance training	-Reprogramming allows partial mission accomplishment and prevents a mission abort

ORGANIZATIONAL MAINTENANCE

Problems	Advantages
-Manning of organizational maintenance teams is very limited and inadequate to supply more than a minimum of maintenance	-No damage occurs from transporting and no time is lost in system removal, since maintenance can be accomplished at this level with the system in place
-Sufficient supply of spare parts at each site is impractical	
-Extensive facilities, tools and test equipment are difficult to supply at each site	
-Down time results from long logistic pipelines and slow delivery of needed replacements	
-Environmental conditions are often extreme	

FIELD MAINTENANCE

Problems	Advantages
-Entire systems, especially missiles, are difficult to move to a base	-Proximity to organizational level considerably shortens logistic pipe-line
-Skilled personnel needed at field level quite often must be dispatched to forward areas to accomplish "brush fire" maintenance	-Since communication is relatively easy, data needed on malfunction may be obtained at the original location
-The areas of responsibility for this level are difficult to define which results in duplication of maintenance at other levels	-Environment in which maintenance is done can be reasonably comfortable
-Many components are coded "Depot Repair Only" even though skills and equipment are available	-More complete facilities, equipment and components are available than at organizational level

DEPOT MAINTENANCE

-Transportation of units for repair decreases their operational availability	-High skills levels are usually available at this level
-Transportation and handling of equipment may cause additional damage	-Since a depot services many units, the high utilization justifies many time, cost and labor saving devices, and allows any or all repairs to be accomplished
-Transportation and handling costs may be more costly than unit procurement	-Controlled environments can be provided for specialized repair at this level
-Unless high utilization is realized, overhead costs can be excessive	-Internal scheduling can be readily accomplished
-Highly skilled personnel are demanded even though they may be needed more at higher maintenance levels	
-Logistics scheduling to return units to service is extremely complex	
-Communication problems increase the difficulty of obtaining malfunction indications from the original location	

EXPLANATION OF TERMS

Adjusting - The process of bringing an out of tolerance condition into tolerance by manipulating a control or controls.

Aligning - The act of bringing two or more components into relationship with each other through mechanical manipulation.

Automatic Testing - A method for localizing a malfunction through automatic equipment to a given level - usually the level at which the malfunctioning unit will be removed and replaced.

Auxiliary Redundancy - A form of redundancy in which two or more non-identical systems, subsystems, components, etc., simultaneously provide a needed function. In case the prime system fails, the remaining system(s) can provide the entire function. An example is the availability of several methods of guidance in a single vehicle.

Back-up Systems - A form of redundancy in which the function is provided, in case of malfunction of the original system, through the use of a complete airborne system as a replacement unit. It is not practical except in cases of inexpensive systems or where repair costs exceed system costs.

Bits and Pieces Maintenance - A maintenance process in which the maintenance is done at the level of the smallest repairable part.

Calibration - The process of aligning or adjusting components to acceptable standards.

Component Testing - A test in which each part of a system is tested individually to find malfunctions. Although usually static, some dynamic measures such as voltages are used.

Confidence Testing - A form of quick automatic testing of selected system elements which, if tested as satisfactory, assure an expected probability of mission success.

Continuous Check - See Continuous Monitoring - Human - Machine

Continuous Monitoring - Human - A process through which the human continuously monitors a machine display in some form in order to detect malfunctions or unusual events in the output.

Continuous Monitoring - Machine - A process by which specified signal outputs of prime equipment are continuously tested to determine malfunction. A built-in warning device indicates malfunction.

Crew Stations Check - A test procedure to assure an acceptable level of systems performance within specified tolerances in aircraft.

Depot Level - The process of overhauling equipment and returning it to a serviceable condition at a specified percent of unit cost.

Field Level - The process of restoring equipment to a serviceable status with specified test and repair equipment within a specified period of time.

Flight Irregularities - The process of recognizing the occurence of a malfunction through unusual reactions of an aircraft, abnormal instrument readings, or sensory cues; visual, audio, proprioceptive, etc.

In-Flight Level - The process of restoring equipment to an operational status within the time and accuracy necessary to provide crew safety and mission success.

Leave Alone - A test philosophy in which no testing is done. It is based on the premise that the testing process itself will introduce malfunctions in equipment.

Maintenance Testing - The process of determining which unit has malfunctioned after a malfunction occurs.

Manual Testing - A method of testing in which each element to be tested is tested by maintenance personnel through individual hook up to a specific test item.

Marginal Testing - A process of testing in which equipment is exposed to abnormal environments and operating conditions as a method of disclosing incipient failures.

Modular Replacement - The process of substituting an identical operating unit for a malfunctioning unit. The unit level is usually between a component and system level.

No Maintenance - A maintenance philosophy in which the system is left alone after having passed a confidence test. It avoids the problem of malfunctions being introduced by maintenance personnel.

Organizational Level - The process of restoring equipment to an operational status within a specified period of time.

Parallel Redundancy - A form of redundancy in which two or more identical systems, subsystems, components, etc., are available to provide a function for which only one element is necessary. Only one element is in use at a time, and the change to the other element, in case of malfunction, is accomplished either through manual or automatic switching.

Parallel Working Systems - A form of redundancy in which two or more identical systems, subsystems, components, etc., simultaneously provide a function which one, by itself, could accomplish. It is based on the premise that there is small likelihood of all redundant elements failing at one time.

Periodic Check - A test procedure which is based on calendar or use time.

Periodic Inspection - An inspection procedure which is scheduled on calendar or use time.

Periodic Maintenance - A Maintenance procedure which is scheduled on calendar or use time.

Periodic Overhaul - A form of maintenance which is performed at depot level and requires a major overhaul and rebuilding of a major system or subsystems.

Pre-Flight Inspection - An inspection procedure which is conducted previous to the first flight of the day.

Pre-Launch Inspection - Same as above for missiles.

Preventive Maintenance - A procedure of inspecting, testing and reconditioning a product at regular intervals according to specific instructions intended to prevent failures in service or to retard wear-out deterioration.

Redundancy-Automatic Switching - A parallel redundancy form in which switching is automatic.

Redundancy-Manual Switching - A parallel redundancy form in which switching is manual.

Remote Ground Switching - A form of parallel redundancy in which switching is accomplished through telemetered or remote means by command signals.

Safety Factors - A form of redundancy in which secondary measures are available to handle functions in case of failure of the prime system. It is usually represented in mechanical system which can be used if hydraulic systems fail, etc. The main difference between this form and Auxiliary Redundancy is that in this form the secondary systems are used only on failure of the prime system, while in Auxiliary Redundancy all are working until failure.

Sequential Degradation Analysis - A form of preventive maintenance which is based on a running analysis of actual deterioration in order to predict remaining service life and consequent replacement schedule.

Servicing - The process of replenishing anything normally consumed in flight or ground operations.

Throw-Away Maintenance - A modular replacement method of maintenance in which the malfunctioning unit is thrown away rather than being returned to field or depot level for repair. Cost and ability to repair are the key decision factors.

Time Scheduled Maintenance - A form of preventive maintenance which is based on predicted life hours for the equipment.

Visual Inspection - The process of looking for apparent or incipient defects in system components.

Walk Around Inspection - A visual inspection conducted previous to take off, to determine obvious sources of malfunctions; leaks, cracks, etc.

SECTION III

DETAILED DESIGN GUIDE

Introduction

Information specific to the detailed design of equipment for maintainability is provided in this section of the Guide. It includes:

- A concise summary of established and available maintainability principles, criteria, and requirements.

- Appropriate and relatively independent headings or topics for the above material.

- An integration of these headings, through cross-referencing and organization, in such a manner that all relevant aspects of a given design problem can be considered.

This section is written in a style and format which should make it maximally useful as a reference for the designer. It is not intended for use as a textbook.

Bibliographic Credits

The material presented in this section was obtained from the sources listed in the Bibliography. Except for the manner of presentation, very little original data is provided, and the authors are heavily indebted to their sources.

However, the manner of presentation often makes it impossible to distinguish source. Therefore, specific credits are given only to acknowledge cases of direct use.

Format

Examples of headings and subheadings used in this section are on the following page. Also indicated are the positions in which the material may be found on each page.

The format is adapted to the nature of the information, however; thus, the subheadings do not occur under every topic, and they are frequently in different order.

Each title is followed by a short description of the type of material discussed under that title.

To provide extra information for the designer, titles such as "Special Applications," "Caution" or "Note" are included under subheadings as necessary.

TOPIC

These are the independent headings referred to on the previous page. The heading is only in the top outer corner of each succeeding page for the topic

DECISION FACTORS:

These are items of information which the user must consider in making specific design decisions. The topic is frequently defined here.

GENERAL REQUIREMENTS:

The requirements and considerations included here relate in general to all design factors of the particular topic.

Specific Requirements:

Included are unique considerations specific to the topic. The heading indicates the specific area covered, such as "Size requirements."

Preference List:

This is provided where appropriate to aid the designer in his selection from available choices. "Types of Fasteners, (in order of preference)," for example.

Related requirements:

This title, which usually occurs under a subheading, is used to indicate requirements (given under other topics) which must be considered, along with the requirements of the topic at hand.

Indexing

The following features are provided to assist the immediate location of topics of interest to the user:

- TIM chart. The Topic Indexing Matrix (TIM), presented on page 157, provides page integration for the major topics and subtopics in the Guide. One axis includes major topics only, while the other axis includes subtopics as well as major topics. The pages where major and subtopics interact are indicated in the respective column-row interspace. In the interspaces where column and row display the same major topic, the pages in which the major topic appears as the title are given.

  Each interspace also includes a letter, "C" (critical) or "I" (important) or "D" (desirable) which indicates the degree to which the designer must consider the interaction. It is suggested that the user enter the Guide through the TIM chart since it provides an indication of the dependence and interaction among design features.

- Subject index. The subject index lists and cross-references all titles, subtitles and major items of interest found in the following pages.

- Table of contents. The table of contents lists each major topic and the page on which it starts.

- Cross-referencing. Cross-referencing within each subsection leads the user and/or calls his attention to other pages intimately related to the topic he is considering.

- Titles. The titles at the top, outside corner of each page will enable the user to quickly locate major topics of immediate interest.

- Underlining. Underlining and paragraph structuring are utilized to the fullest practical extent to allow scanning and thus facilitate the location of detail information.

ACCESS REQUIREMENTS

DECISION FACTORS:

Accessibility is a prime maintainability problem. Ineffective maintenance is often the result of inaccessibility. The technician will tend to delay or omit maintenance actions, to make mistakes, and to accidentally damage equipment, if he cannot adequately see, reach and manipulate the items on which he must work.

Access must be provided to all points, items, units and components which require or may require testing, servicing, adjusting, removal, replacement, or repair. The type, size, shape and location of access should be based upon a thorough understanding of the:

a. Operational location, setting and environment of the unit.
b. Frequency with which the access must be entered.
c. Maintenance functions to be performed through the access.
d. Time requirements for the performance of these functions.
e. Types of tools and accessories required by these functions.
f. Work clearances required for performance of these functions. (See p.47)
g. Type of clothing likely to be worn by the technician.
h. Distance to which the technician must reach within the access.
i. Visual requirements of the technician in performing the task.
j. Packaging of items and elements, etc., behind the access. (See p.54)
k. Mounting of items, units and elements, behind the access. (See p.56)
l. Hazards involved in or related to use of the access.
m. Size, shape, weight and clearance requirements of logical combinations of human appendages, tools, units, etc., that must enter the access.

TYPES OF ACCESS (In order of preference):

1. Uncovered or exposed equipment. When structural, environmental, operational, and safety conditions permit, equipment should be left exposed for maintenance. This is particularly true of test and service points, maintenance displays and controls and rack-mounted "black boxes."

2. Semi-exposed equipment. Semi-exposure can be accomplished by means of:
   a. Pull-out racks or drawers. (See p.51)
   b. Full-length doors on cabinets or equipment racks. (See p.85)
   c. Quick-opening hoods or covers. (See p.86)
   d. Easily and quickly removable dust-covers and cases. (See p.84-86)

3. Uncovered, limited access openings. Uncovered openings can be used only when environmental control is not required and when danger to equipment or personnel is minimal. Work clearances around mounts, components, etc., should be considered as uncovered, limited access openings subject to the size requirements provided below.

4. Covered, limited access openings. Covered accesses must be evaluated in terms the types of covers and fasteners employed. (See "Covers and Cases," p.82 and "Fasteners," p.42).

5. Stress doors. Stress doors are usually required in high performance equipment, but should be avoided wherever possible. When required, the accessibility of stress doors can be improved by selection of fasteners. (See p.86)

6. Riveted panels and doors. Riveted panels are never acceptable as access points. Overall layout and design of equipment should not require removal of permanently attached structures even for infrequent maintenance.

GENERAL ACCESS REQUIREMENTS:

1. Where possible and feasible, design for accessibility on a grand scale:
   a. Use split-line design.
   b. Use hinged or removable chassis.
   c. Design major units and assemblies (particularly engines, turbines, etc.) with removable housings to make complete inspections possible.
   d. Hinge aircraft or missile skin for ease of access to assemblies and accessories during major checkouts, turn-arounds, etc.
   e. Correlate the design of unit accessibility features with the accessibility requirements of the over-all system.

2. Design, locate, cover, and fasten accesses in such a manner as to avoid the necessity for removing components, wires, etc., to reach the item requiring maintenance.

3. Design so that the removal of any replaceable unit requires opening of only one access, unless the accesses are of the latched and hinged door type.

4. Locate items requiring visual inspection (hydraulic reservoirs, guages, etc.) so they can be observed without the removal of panels or other components.

5. Line the edges of accesses with internal fillets or other suitable protection wherever sharp edges might otherwise injure technicians, hoses, etc.

6. Provide visual access for all maintenance operations requiring visual control and, particularly, where hazards can be encountered within the access. Do not require the technician to work blindly.

7. Where accesses are located over unavoidable dangerous mechanical or electrical components, design the access door so that when opened it turns on an internal light, and provides a high visibility warning label on the door.

8. Provide safety interlocks on accesses leading to equipment with high voltages. If the equipment circuit must be "On" during maintenance, provide a cheater switch that automatically resets when the access is closed.

9. Provide self-sealing tanks with an access of such size and location that the entire interior of the tank is available for inspection, cleaning or other maintenance without removal of the tank.

SHAPE OF ACCESSES:

Make accesses whatever shape is necessary to permit easy passage of the required items, body appendages, implements, etc. Consider:
   a. Dimensions of the various units that must be replaced through the access.
   b. Protuberances, attachments, handles, etc., on these units.
   c. Methods of grasping units during removal, and the required clearances.
   d. Requirements for work clearance for work within the compartment.
   e. Requirements for visual control of functions performed within the compartment.

Accesses need not be of regular geometric shapes; the designer should consider irregular shapes that will best satisfy both structural and accessibility requirements.

LOCATION OF ACCESSES:

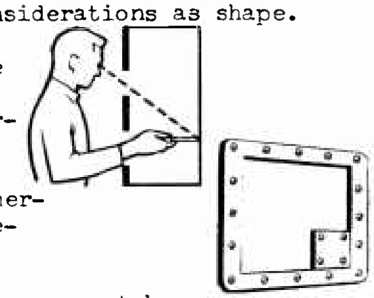
Locate accesses:

a. Only on unit faces that will be accessible in normal installation.
b. To permit direct access and maximum convenience for job procedures.
c. On the same face of the equipment as the related displays, controls, test points, cables, etc.
d. Away from high voltages or dangerous moving parts, or provide adequate insulation, shielding, etc., around such parts to prevent injury to personnel.
e. So that heavy units can be pulled out rather than lifted out.
f. In accordance with the "mobile work space requirements" on p.50)
g. In accordance with the work space requirements on p.47.
h. So that the bottom edge of a limited access is no lower than 24 inches or the top edge no higher than 60 inches from the floor or work platform
i. To conform to heights of work stands and carts related to use of the access.

SIZE OF ACCESSES:

The size of the access should be dictated by the same considerations as shape.

In general, one large access is preferable to two or more small ones; but where structural or other considerations require, visual and physical access may be provided separately (as shown at right).

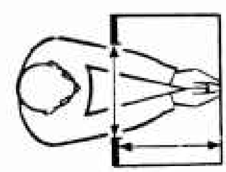


Where stress doors are employed, or access covers are otherwise difficult to remove, provide a smaller access to frequently used test or service points.

CAUTION: The minimal access sizes prescribed below assume no protuberances, no potentially injurious contacts, and no protective coverings or padding; therefore, these dimensions must be increased to allow for such conditions where they exist.

WHOLE BODY ACCESSES: (See "Mobile Work Space" p.50)

MINIMAL TWO-HAND ACCESS OPENINGS:

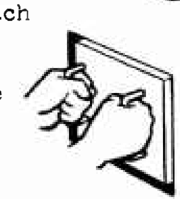


Reaching with both hands to depth of 6 to 25 inches:

Light clothing:	5" high by 8" or 3/4 depth of reach.*
Arctic clothing:	7" high by 6" plus 3/4 depth of reach

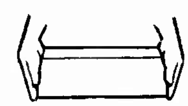
Inserting box grasped by handles on the front:

1/2" clearance around box, assuming adequate clearance around handles. (See "Handles" p.52)



Inserting box with hands on the sides:

Light clothing:	Width:	Box plus 4-1/2"
	Height:	5" or 1/2" around box.*
Arctic clothing:	Width:	Box plus 7"
	Height:	8.5" or 1/2 around box.*



NOTE: If hands will curl around bottom of box, allow an additional 1-1/2" in height for light clothing, 3" for arctic clothing.

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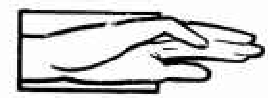
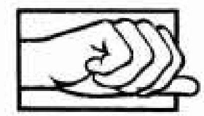
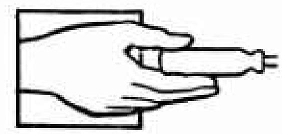
*Whichever is larger.

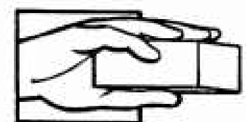
MINIMAL ONE HAND ACCESS OPENINGS:

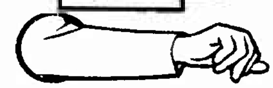
	Width	Height
Empty hand to wrist:		
Bare hand, rolled:	3.75" sq. or dia.	
Bare hand, flat:	2.25" x 4.0" or 4.0" dia.	
Glove or mitten:	4.0" x 6.0" or 6.0" dia.	
Arctic mitten:	5.0" x 6.5" or 6.5" dia.	
Clenched hand, to wrist:		
Bare hand:	3.5" x 5.0" or 5.0" dia.	
Glove or mitten:	4.5" x 6.0" or 6.0" dia.	
Arctic mitten:	7.0" x 8.5" or 8.5" dia.	
Hand plus 1" dia. object, to wrist:		
Bare hand:	3.75" sq. or dia.	
Glove or mitten:	6.0" sq. or dia.	
Arctic mitten:	7.0" sq. or dia.	
Hand plus obect over 1" in dia, to wrist:		
Bare hand:	1.75" clearance around object.	
Glove or mitten:	2.5" clearance around object.	
Arctic mitten:	3.5" clearance around object.	
Arm to elbow:		
Light clothing:	4.0" x 4.5" or 4.5" dia.	
Arctic clothing:	7.0" sq. or dia.	
With object:	Clearances as above.	
Arm to shoulder:		
Light clothing:	5.0" sq. or dia.	
Arctic clothing:	8.5" sq. or dia.	
With object:	Clearances as above.	











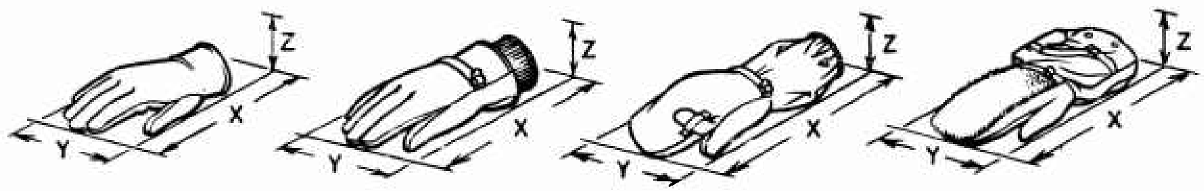
MINIMAL FINGER ACCESS TO FIRST JOINT:

Push button Access:	Bare hand:	1.25"	dia.
	Gloved hand:	1.5"	dia.
Two finger twist access:			
	Bare hand:	2.0"	dia.
	Gloved hand:	2.5"	dia.
Vaccum tube insert (tube held as at right):			
	Miniature tube:	2.0"	dia.
	Large tube:	4.0"	dia.

CLEARANCES FOR THE GLOVED HAND:*

The following table provides dimensions, in inches, for various types of hand coverings during defined functions. These dimensions are generalizable to any situation requiring a definable hand clearance or to similar types of protective hand coverings.

CAUTION. These dimensions are minimal and must be increased to allow for additional encumberances, variations in movement, or to allow clearance between the gloved hand and hazards, items or protuberances which would restrict movement.



Hand Attitude	Anticontact Glove X	Anticontact Glove Y	Anticontact Glove Z	Wet-cold Glove X	Wet-cold Glove Y	Wet-cold Glove Z	Wet-cold Mitten X	Wet-cold Mitten Y	Wet-cold Mitten Z	Arctic Mitten X	Arctic Mitten Y	Arctic Mitten Z
Extended flat:	10.3	4.5	2.5	10.5	5.5	3.0	14.0	5.8	3.2	16.4	5.2	3.6
Closed as fist:	7.0	5.0	3.3	7.3	5.8	3.7	11.5	5.8	3.8	14.3	5.2	5.4
Grasping handle;												
.25" diameter:	7.0	5.0	3.5	7.3	5.5	3.5	11.0	5.7	4.2	14.0	5.5	4.5
1.0" diameter:	7.0	5.0	3.5	7.3	5.3	4.0	11.0	5.2	4.5	14.7	5.2	4.5
2.0" diameter:	7.5	4.5	4.2	8.0	4.7	4.0	12.0	5.2	4.7	15.0	5.4	5.0
Grasping knob;												
.25" diameter:	8.0	3.8	4.3	9.0	4.6	4.0	11.5	5.0	4.2	15.5	4.8	4.5
1.0" diameter:	9.0	3.5	4.0	9.0	4.5	4.0	12.0	5.0	4.0	15.8	4.8	4.8
2.0" diameter:	9.5	3.7	3.7	9.2	4.5	4.2	12.5	4.6	4.4	16.0	4.7	4.5

*The largest dimension in each column is underlined.
For bare hand dimensions, see p.139.
Data adapted from Ref. 20 and 33.

WORK SPACE REQUIREMENTS

DECISION FACTORS:

In order for the technician to accomplish required maintenance, sufficient work space must be provided for him to perform the functions related to or involved in this maintenance. The layout and design of equipment should always be preceded by a task analysis of at least sufficient thoroughness to allow determination of:

a. Points where maintenance is or may be required.
b. Approximate body positions necessary to perform this maintenance.
c. Requirements for space and clearances to accomodate this body position and the required movements.
d. Requirements for access or passage to the work point.
e. The size and weight of tools, loads, etc. to be carried to the work point.
f. Requirements for wrenching space, grasping space, etc., about the items to be manipulated--e.g., fasteners, tools, modules, covers, etc.
g. Requirements for space and light to enable the technician to see and control these manipulations. (See "Environment," p.130)

CAUTION: The dimensions provided for work space and clearance in the following pages, assume only the functions described and must be suitably increased if:

a. Loads, vehicles, or equipment other than those described must also pass through the spaces described.
b. Doors, shelves, covers or other protuberances must open into or occupy some of the space described.
c. Additional clearance must be allowed to prevent technicians from contacting electrical, mechanical, or chemical hazards.
d. Additional clearance must be allowed to accomodate work stands, test equipment, tool cases, etc. (See "Protection and Safety," p.69 and 99)

GENERAL REQUIREMENTS:

a. Work space should allow the technician to change posture if the maintenance task requiring kneeling, crawling, or crouching is a prolonged one.
b. Provisions should be made to protect the technician from hazards considered under "Protection and Safety," on p.99.
c. The following should be provided at the work place wherever practicable to assist the technician in the performance of maintenance:
    (1) Auxiliary hooks, holders, lights, outlets, etc.
    (2) Auxiliary stands or shelves built into the equipment to support test equipment, removable units, or items to be repaired.
    (3) Lattice work, low cabinets, mirrors, open space, etc. as necessary to allow visual contact with related displays, moving parts, etc.
    (4) Features which allow or facilitate communication among maintenance team members; teams which can communicate, work faster and are better satisfied than those which cannot.

Walking surface requirements:

a. Non-skid treads, expanded metal flooring, or abrasive coatings should be provided on all surfaces which may be used for walking, climbing, or footholds.
b. These surfaces should be perforated or sloped to allow for drainage, and should be durable enough to resist wear and subsequent slipperiness.
c. Tractor hoods and top surfaces of other equipment should be reinforced and provided with non-skid surfaces whenever they may be used as work platforms.

STANDING WORK SPACE AND CLEARANCE REQUIREMENTS:

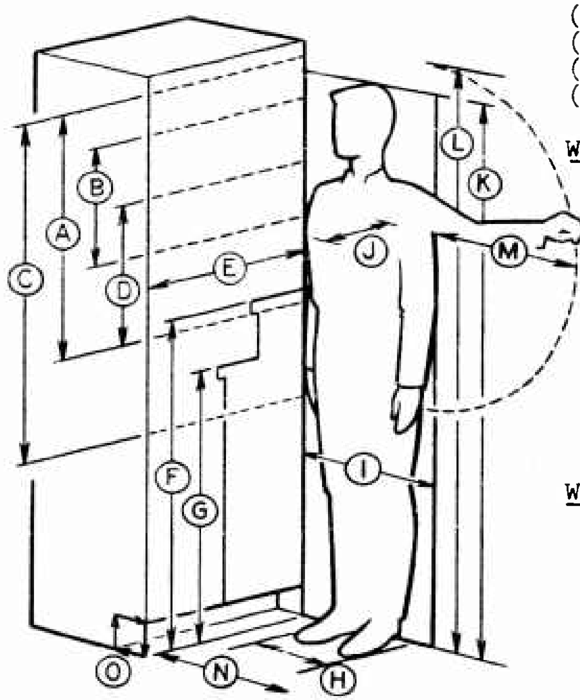
Wherever possible, design should allow the performance of routine, frequent, and/or short-term maintenance from a standing position. Minimum requirements are provided below. Capital letters refer to the illustration.

Visual and manipulation work space requirements: (Ref. 28)

Displays, markings, etc., which require reading from the standing position should be within the following distances from the floor:
- A. Maximum limits: 40-70", for all visual displays on vertical panels.
- B. Optimum limits: 48-64", for key, critical or precise reading items.

Controls, test points, fasteners, etc., requiring manipulation from the standing position should be within the following distances from the floor:
- C. Maximum limits: 30-70", for all controls, etc.
- D. Optimum limits: 40-55", for key, critical, or high-force controls.

Length of work area (E) for standing work is limited by time to move between points and/or requirements for reach or visual contact between points. For work at a given position, distances from the center line should be:



(1) 22.5" for all related work points.
(2) 17.0" for key manipulation points.
(3) 11.5" for key visual work points.
(4) See "Controls and Displays," on p.114.

Work bench requirements:

Work surfaces provided for standing positions should be of the following sizes:
- F. Standard work benches:
  - (1) Height: 36" above floor.
  - (2) Width: 39" maximum.
  - (3) Length: As required.
- G. Podium type work benches or control surfaces
  - (1) Height: 41" above floor.
  - (2) Width: 36" maximum.
  - (3) Length: 44" maximum.

Work clearance for standing operations:

	Min	Best	Arctic
H. Walking space width:	12"	15"	15"
I. Passing body width:	20"	32"	32"
J. Passing body depth:	13"	15"	15"
K. Overhead clearance:	73"	80"	76"
L. Maximum overhead reach:		76"	73"
M. Maximum depth of reach:		23"	23"

Standing space (N) of at least 30" and preferably 36" should be provided before all work surfaces where appropriate.

Kick space (O), 4" high by 4" deep, should be provided wherever personnel stand or sit close to cabinets, benches or other work surfaces.

SEATING WORK SPACE AND CLEARANCES:

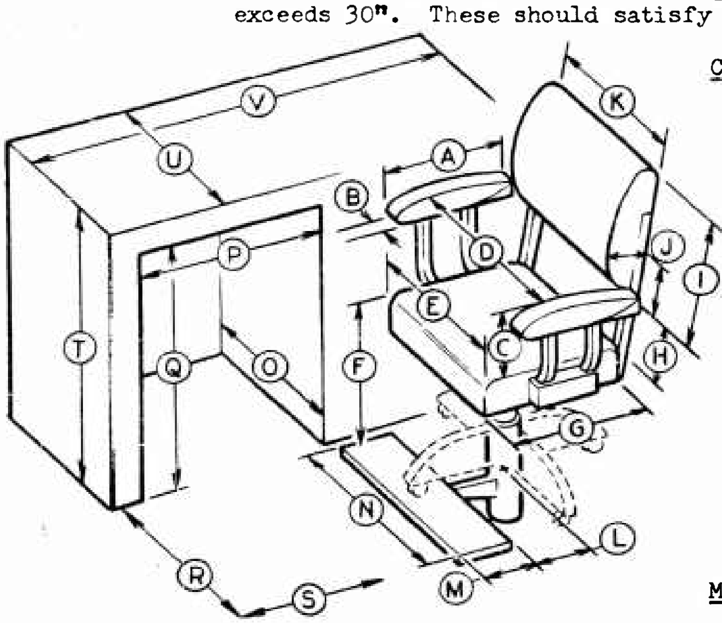
Chairs should be provided whenever personnel are required to perform in the sitting position for more than one hour at a time or more than 20% of the time.

Stools or benches will suffice for other sitting operations. These should also satisfy the requirements below wherever feasible, but may be as small as 10" in depth or diameter. Fold-down benches should be provided wherever practical to support the technician during maintenance operations.

General seat requirements: A good seat should be designed so that the cushioned areas: (See Ref. 10 and 40).

a. Are fairly flat and firm, but soft enough to allow limited deformation.
b. Provide shock absorber effect by resilient material under the cushion.
c. Support body weight primarily on the two bony points of the pelvis.
d. Are tilted 5-7° to allow seat rather than muscles to support the back.
e. Follow inward curve of the lower back, to relieve back muscles.
f. Are laterally curved to fit lower back, but do not restrict movement.

g. Do not place pressure under thighs, which causes numbness and fatigue.
h. Are perforated and/or ventilated to prevent "hotness" or "sweatiness."
i. Allow sitter to shift positions; no one position is comfortable long.
j. Provide arm rests to help elbows support some of the upper body weight; these should be removable and undercut for hips and thighs.
k. Provide foot rests wherever seat height exceeds 18" or work surface height exceeds 30". These should satisfy requirement "F" below.



Chair dimensions:		Fixed	Adjust.*
Arm rests:			
A.	Length:	10"	± 2"
B.	Width:	2"	
C.	Height:	8.5"	± 2.5"
D.	Separation:	18"	
Seat:			
E.	Width:	16"	
F.	Height:	18"	± 2"
G.	Depth:	16"	
Back rest:			
H.	Space:	6"	± 2"
I.	Height:	15"	
J.	Max curve:	4"	
K.	Width:	16"	
Footrests (where required):			
L.	From center	7"	
M.	Width:	6"	
N.	Length:	10"	

Desk or work surface dimensions:	Min	Best
T. Height of work surface:	29"	30"
U. Width of work surface		
(1) Elbow rest alone:	4"	8"
(2) Writing surface:	12"	16"
(3) Desk work area:		36"
V. Length of work area:	30"	--

Minimum clearance requirements:	
O. Kneehole depth:	18"
P. Kneehole width:	20"
Q. Kneehole height:	25"
R. Desk to wall:	32"
S. Lateral work clearance:	
(1) Shoulders:	23"
(2) Elbows:	25"
(3) Best overall:	40"

*Adjustment range. Adjustability is preferred for these dimensions.

MOBILE WORK SPACE REQUIREMENTS:

When technicians are required to work in or pass through limited spaces, the appropriate values should be selected from those provided below to identify minimum clearances for such work or passage (see drawings below):

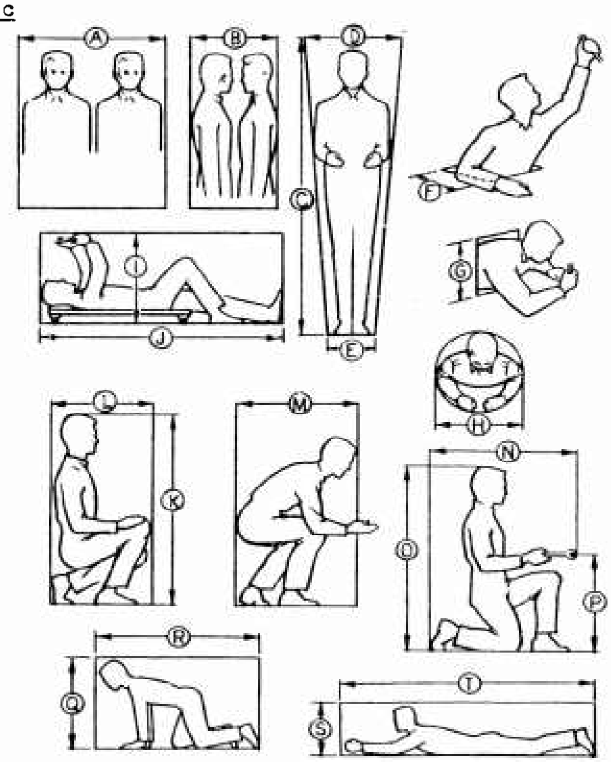
		Min	Best	Arctic
A.	Two men passing abreast:	42"	54"	60"
B.	Two men passing facing:	30"	36"	36"
	Catwalk dimensions:			
C.	Height:	63"	73"	75"
D.	Shoulder width:	22"	24"	32"
E.	Walking width:	12"	15"	15"
F.	Vertical entry hatch:			
	Round or square:	18"	22"	32"
G.	Horizontal entry hatch:			
	Shoulder width:	18"	22"	32"
	Height:	15"	20"	24"
H.	Crawl through pipe:			
	Round or square:	25"	30"	32"

Distribution parameters significant to tradeoffs in work clearance for lightly clad technicians:*

Dimensions:	Mean	S.D.
Max body depth:	11.5	.88
Max body breadth:	20.9	1.19
Overhead grasp:	82.5	3.33
Kneeling height:	32.0	1.56
Kneeling length:	43.0	3.26
Crawling height:	28.4	1.30
Crawling length:	53.2	2.61
Prone height:	14.5	1.28
Prone length:	90.1	3.41

*Adapted From Ref. 26.

		Min	Best	Arctic
	Supine work space:			
I.	Height:	20"	24"	26"
J.	Length:	73"	75"	78"
	Squatting work space:			
K.	Height:	48"	--	51"
L.	Width:	27"	36"	40"
	Optimum display area:	27-43"		
	Optimum control area:	19-34"		
	Stooping work space:			
M.	Width:	36"	40"	44"
	Optimum display area:	32-48"		
	Optimum control area:	24-39"		
	Kneeling work space:			
N.	Width:	42"	48"	50"
O.	Height:	56"	--	59"
P.	Optimum work point:		27"	
	Optimum display area:	28-44"		
	Optimum control area:	20-35"		
	Kneeling crawl space:			
Q.	Height:	31"	36"	38"
R.	Length:	59"	--	62"
	Prone work or crawl space:			
S.	Height:	17"	20"	24"
T.	Length:	96"	--	--



DRAWER AND RACK REQUIREMENTS

DECISION FACTORS:

Pull-out, roll-out, or slide-out drawers, shelves, racks or other hinged or sliding assemblies should be provided as necessary and wherever practicable to:

a. Optimize work space, tool clearance, and accessibility.
b. Reduce the need for the technician to handle fragile or sensitive items.
c. Facilitate the handling and/or positioning of heavy or awkward items.
d. Facilitate maintenance of items which must be frequently moved from the installed position for checking, servicing or repair.

Related requirements:

Where such features are involved, these drawers and racks must be designed in accordance with the discussions under:

a. "Lead requirements," p. 80, when leads are attached to the assembly.
b. "Connector requirements," p. 68, when disconnection is required.
c. "Handling requirements," p. 60, when the assembly must be handled.
d. "Fastener requirements," p. 62, when the assembly is fastened.

GENERAL DESIGN REQUIREMENTS:

Such drawers, racks, etc., should be so designed that:

a. A minimum number of operations are required to open or release them.
b. They operate with a force less than 40 lbs.
c. A smooth operating bearing assembly facilitates the operation, as needed.
d. They lock automatically in both the servicing and operation positions.
e. Handles are provided as necessary to facilitate operation and handling. (See "Handle Requirements," p.52)
f. Assemblies may be opened without breaking internal connections which are necessary for the required maintenance.
g. Extension cables or hoses are provided as necessary to allow completely removable assemblies to be checked in a convenient location.
h. Guards and shields are provided as necessary to prevent damage to fragile or sensitive parts during movement of the assembly.
i. Rests, limit stops, guards and/or retaining devices are provided as part of the basic chassis. These devices should:
   (1) Prevent the assembly from being dropped.
   (2) Prevent heavy assemblies from tipping the equipment.
   (3) Allow complete and convenient removal of the assembly.
   (4) Allow the assembly to open its full distance and remain open without being held.

Where internal connection is not required during maintenance, connectors to the drawer, shelf, etc., may be attached to the assembly itself, so that closing the assembly effects connection. This requires that:

a. Connector parts be mounted on the assembly and rear wall.
b. Locks be provided to ensure that connectors remain engaged.
c. Guides be provided to ensure proper orientation of the assembly prior to pin engagement.
d. Insulation be provided as necessary to ensure safety.

HANDLE REQUIREMENTS

DECISION FACTORS:

The dimensions, location and positioning of handles are functions of the:

a. Weight of the item or unit.
b. Number of men, or hands, required to lift or carry the item.
c. Type of clothing and gloves worn by these men.
d. Operational position of the item relative to other items and obstructions.
e. Manner in which the item is to be handled or positioned.
f. Distance over which the item must be carried.
g. Frequency with which the item must be handled or carried.
h. Additional uses the handles could serve.

GENERAL REQUIREMENTS:

1. Handles should be provided on all packages, units, components, and covers when these items:
   a. Are difficult to grasp, remove, or carry.
   b. Are to be frequently handled or carried.
   c. Weigh over 10 pounds.
   d. Have fragile components which might be used as hand-holds.

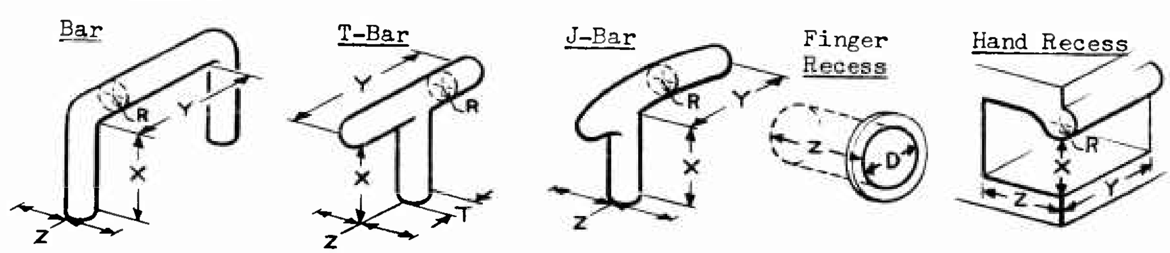
2. Hoist lugs (lifting-eyes) should be provided on all units weighing more than 150 pounds. Mark "LIFT HERE" adjacent to each lug, and provide a minimum of 4 inches about the eye, for convenient use.

3. Handles, lugs, and other handling gear (casters, push bars, etc.) should be permanent parts of the unit case.

4. Molded handles should be provided when items must be carried frequently or for long periods. (These prevent undue side pressure on the fingers.)

5. Recessed, concealed or folding handles may be used to conserve space; but they must be accessible without tools and must remain securely folded when not in use.

TYPES OF HANDLES:



CURVATURE OF HANDLE OR EDGE: (See drawings)

Weight of item	Radius of curvature (minimum)
Up to 15 lbs:	R - 1/8 in.
15 to 20 lbs:	R - 1/4 in.
Over 20 lbs:	R - 3/8 in. but 1.5 in.
T-Bar post:	T - 1/2 in.

Gripping efficiency is best if fingers can curl around handle or edge to an angle of 120 degrees or better.

DIMENSIONS OF HANDLE:

Type of Handle:	Bare Hand X	Bare Hand Y	Bare Hand Z	Gloved Hand X	Gloved Hand Y	Gloved Hand Z	Arctic Mitten X	Arctic Mitten Y	Arctic Mitten Z
				Expected User Clothing					
One-hand bar	2.0	4.25	2.0	2.5	4.75	2.0	3.0	5.5	3.0
Two-hand bar	2.0	8.5	2.0	2.5	9.5	2.0	3.0	11.0	3.0
Two-finger bar	1.25	2.5	1.5	1.5	3.0	1.5	Don't use		
One-hand recess	2.0	4.25	3.5	2.5	4.75	4.0	3.0	5.5	5.0
Two-finger recess	1.25-dia.		2.0	1.5-dia.		2.0	Don't use		
One-finger recess	1.25-dia.		2.0	1.5-dia.		2.0	Don't use		
Finger-tip recess	0.75-dia.		0.5	1.0-dia.		0.75	Don't use		
T-bar	1.5	4.0	1.5	2.0	4.5	2.0	Don't use		
J-bar	2.0	4.0	2.0	2.0	4.75	2.0	3.0	5.0	3.0

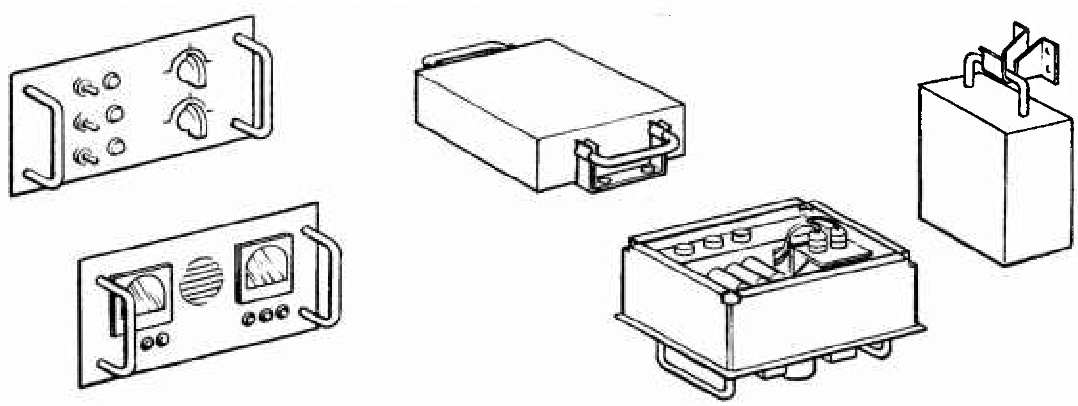
LOCATION OF HANDLES:

1. Locate single handles over the center of gravity.
2. Locate two or four handles at equal intervals from the center of gravity.
3. Place handles where they do not interfere with operation or maintenance.
4. Provide at least a 2 inch clearance between handles and obstructions.
5. Place handles on the front panel if an item must be pulled from the rack.
6. Locate and position handles so they can be held comfortably.
7. Locate handles so the carried item will ride clear of the carriers legs.

ADDITIONAL USES OF HANDLES: (As illustrated below)

Handles may be designed and located to:

a. Guard against inadvertent actuation of controls.
b. Protect delicate parts or instrument faces.
c. Serve as locking devices to secure components in place.
d. Serve as protective supports or stands for components (e.g., can be used as maintenance stands when items are inverted).



MOUNTING AND PACKAGING REQUIREMENTS

DECISION FACTORS:

The majority of parts, units, and assemblies can be located and packaged in a variety of ways and places. The final arrangement should be based upon the following factors:

a. Accessibility preferences and requirements as discussed on p.42-46.
b. The considerations discussed under "Unitization," on p.122.
c. The considerations discussed under "Standardization," on p.120.
d. Reliability figures and factors, as a basis for access requirements.
e. Operating stress, vibration, temperature, etc. (See "Environment," p.126)
f. Producibility and manufacturability factors and requirements.
g. Requirements for built-in test and malfunction circuits or indicators.

h. The peculiar characteristics of each item, unit or module, particularly:
   (1) Item size, weight, and clearance requirements.
   (2) Item fragility or sensitivity and resultant protection needs.
   (3) Item servicing, adjusting or repair needs and procedures.
   (4) Clearance requirements for removing and replacing each item.
   (5) Tool access and clearance requirements for each item fastener, connector, test or service point, etc.
   (6) Specific phenomena such as critical lead length, weight balance, heat dissipation, inductance, etc., requirements.

LAYOUT AND PACKAGING REQUIREMENTS:

The layout, packaging and mounting of units, assemblies, components and/or parts should be designed to maximally facilitate the required or expectable maintenance operations, and specifically to:

a. Satisfy the priorities discussed under "Decision Factors," on p.122.
b. Minimize place to place movement of the technician during servicing, checkout, or troubleshooting.
c. Minimize the need for the technician to retrace movements or steps during servicing, checkout, or troubleshooting.
d. Satisfy related requirements, such as those discussed under:
   (1) "Accesses," on p. 42-46.
   (2) "Lines and cables," on p. 77-81.
   (3) "Test and service points," on p. 87-93.

General layout should systematically follow one or logical combinations of the methods below (listed in order of preference):

1. Logical flow packaging:
   a. Circuits, parts, and components are packaged and located in an arrangement parallel to their functional relationships as established by block diagraming.
   b. Methods and subassemblies are selected so that only single input and output checks are necessary to isolate a fault within an item.
   c. Clear indication is given of the uni-directional signal flow within a given piece of equipment.

2. Circuit packaging:
   a. All parts of a given circuit, or logically or generally related groups of parts, are located in a common volume.
   b. Each circuit is placed in a separate module, while the tube associated with it is placed on top of the module.

c. The circuit should consist of a single terminal board or module of the plug-in type when practicable. (See "Unitization," on p.122)
d. Plug-in printed circuit boards should be structurally rigid and easy to remove and replace.

3. Component packaging:
   a. All similar components are found in one place on the equipment.
   b. Relays are congregated in a single or small number of relay panels.
   c. Resistors, condensers, tube-sockets, etc., are segregated in a minimum number of locations on subassemblies or terminal boards.
   d. Inexpensive components are placed on separate plug-in type boards mounted beneath the chassis.
   e. Multiplicities of similar parts (tubes, etc.) that are likely to require replacement at the same time are grouped together.
   f. Components are segregated on the basis of significant variations in the required maintenance tasks. For instance, items which are to be cleaned by different methods (steam, gunk, solvent, etc.) are packaged so cleaning is possible with minimum masking.

Layout should further facilitate maintainability, by:
   a. Minimizing criss-crossing of signals between components.
   b. Minimizing the number of component or unit inputs and outputs.
   c. Packaging the equipment so the technician has the option of replacing an individual item of a group, or the whole group.
   d. Providing new fastener or bracket assemblies on spare components, where the old ones are likely to be lost or damaged in removal.
   e. Avoiding sequential assembly that requires sequential disassembly to accomplish maintenance.
   f. Mounting parts on a two-dimensional surface--i.e., not "stacked" so the lower layer is supporting the upper layer.
   g. Mounting parts on one side of the board with wiring on the other side and making electrical connections through the board.
   h. Using sliding drawers or racks, or other hinged assemblies, to allow maximum accessibility. (See "Drawers and Racks," on p.51)
   i. Employing external pods or packages when internal space is limited. Such units should be readily removable (or jettisonable if on aircraft).
   j. Being organized according to maintenance specialties, so that maintenance performed by one specialist does not require removal or handling of equipment maintained by another specialist--particularly where such equipment is of a critical nature or its maintenance requires highly specialized skills.

MOUNTING REQUIREMENTS:

Related requirements:

Parts, units, assemblies, etc., should be mounted so that:

a. The manner of mounting satisfies "Accessibility requirements," on p. 42.
b. Connectors employed satisfy preferences and requirements on p. 72.
c. Clamps employed satisfy "Clamp requirements" discussed on p. 78.
d. Fasteners employed satisfy preferences and requirements on p.64.
e. Mounts are of the simplest type possible, consistent with stress requirements.

Mounting fixture requirements:

Mounting fixtures--engine rails, slide rails, rollers, brackets, etc., should be designed so:

a. Only interconnecting wire and structural members are permanently attached to units; all other fixtures should be removable.
b. Fixtures which are built-in to the chassis are either strong enough to withstand usage over life of the system or are removable.
c. Mounting is compatible with the size and weight of the part, to prevent lead breakage or similar damage from fatigue under vibration, handling stress, etc.

Straps and brackets should be used:

a. Which are thick or rounded enough so they have no sharp edges.
b. Which are shorter than mounted units, to provide a clamping action.
c. As necessary for tying down large components.
d. Particularly to support items mounted on the underside of assemblies.
e. Instead of cantilever brackets for mounting parts.

f. As necessary to prevent the mounted item from sliding or jumping out of the position. "U" straps should only be used to "tie-down" components, not to secure or support them.

g. Which are twist- or push-to-lock mounting type for small components; such brackets should be designed so:
   (1) Locking studs are visible when the component is in place.
   (2) Locking screws or dimples are provided as necessary to ensure security of the mount.

Alignment pins and guide requirements:

Supports, guides, and guide pins should be provided as necessary or practicable to assist handling, aligning and positioning of units.

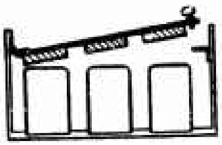
a. Provide alignment pins or slide assemblies rather than allow electrical connections to bear shock and vibrational loads.
b. Use bottom-mounted aligning pins for components which are light enough to be lifted and positioned easily--i.e., weigh less than 20 lbs.
c. Do not use bottom-mounted aligning pins for heavy components.

d. Use side-aligning devices or brackets for heavy components, so that the component can be slid rather than lifted into and out of place.
e. Ensure that the weight of the unit does not hang on the guide-hold flange, causing damage to either the unit or the guide.
f. Provide locking pins, as necessary, on the rear of each chassis to effect proper alignment and reduce chassis strain under vibration.

Shock mounts should be used, as necessary, to:

a. Eliminate vibrational fluctuations in displays, markings, etc.
b. Protect fragile or vibration-sensitive components and instruments.
c. Control sources of high or dangerous noise and vibration.
d. Minimize the overall noise level where desirable.

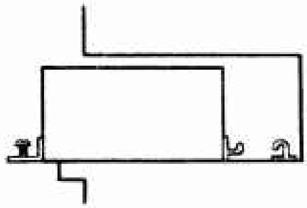
Hinged bars are useful for tying down and permitting access to a number of small components at one time. Such bars should be padded or provided with springs as necessary to prevent damage to the items thus secured.



Where rigid mounting may result in damage to components, use a device which permits some flexibility. For example, a frequent cause of thread-stripping of "T" fittings is the rigid mounting of the fittings.

Where blind mounting is required, secure the inaccessible side with mounts which:

a. Allow exceptionally easy mating.
b. Do not require access--such as friction lugs, tongue and groove fittings, etc.



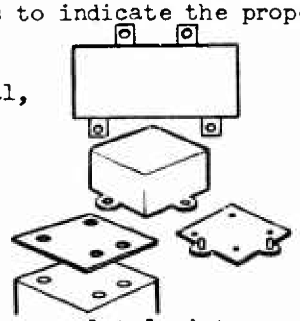
Mounting error prevention requirements:

Design for mounting of components, modules and parts should be such as to prevent their being inadvertently reversed, mis-mated or misaligned during installation or replacement.

Designs, mockups, manufacturing processes, etc., should be continually reviewed to identify and correct or compensate for all potential sources of such errors.

Design should make such errors physically impossible, by:

a. Using preventive methods discussed under "Connectors," on p. 70.
b. Coding, labeling or keying symmetrical components to indicate the proper orientation for mounting or installation.
c. Providing mounting brackets which are asymmetrical, to prevent incorrect mounting, as at right.
d. Providing guide alignment brackets which permit mounting in only one position, as at right.
e. Providing asymmetrical mounting holes, studs, or alignment pins, as at right.



Components of the same form, function and value should be completely interchangeable throughout the system, or related systems.

Components of the same or similar form, but of different functional properties, should be:

a. Mounted with standard orientation throughout the unit.
b. Readily identifiable, distinguishable, and NOT physically interchangeable. (See "Interchangeability," p. 125)

CODING AND LABELING REQUIREMENTS:

The rapidity, ease and accuracy of maintenance, particularly troubleshooting, are proportional to the amount of color coding, marking and labeling employed. These are the most direct links between the designer and repairman, and should be used as fully as possible to explain arrangement, functions, and relationships among items. Some studies have shown the savings in troubleshooting time to be as high as 50% for coded vs. uncoded equipment.

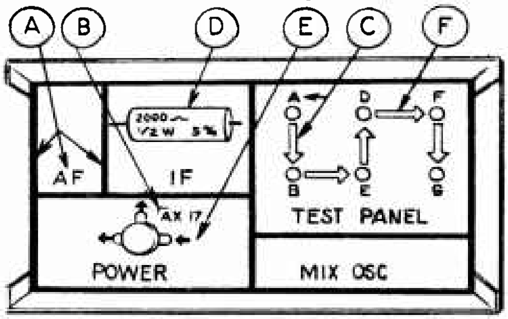
There are no hard and fast rules for coding and labeling as a function and/or part of packaging; the effectiveness of such efforts depends largely upon the care and ingenuity of the planner. But the following are useful guides:

Compatibility: Codes and labels used on and within equipment packages must be:

a. In accordance with the requirements under "Coding and Labeling," on p.71.
b. In accordance with test and service point coding and labeling as on p.89.
c. Consistently and unambiguously used throughout the system.
d. Of such a nature as to be easily read and interpreted.
e. Durable enough to withstand expected wear and environmental conditions.
f. Coordinated and compatible with:
   (1) Codes and labels on related test and service equipment.
   (2) Other coding and labeling within the system.
   (3) Related job aids, instructions, handbooks and manuals.

Identification: Codes and labels should be provided on and within the packaging arrangement as necessary to: (See illustration below and Ref. 22)

A. Outline and identify functional groups of equipment.
B. Identify each item or part by name or common symbol.
C. Identify each test or service point, and the sequence in which used.
D. Identify the value and tolerances of parts such as resistors; this identification should be direct rather than in color code where possible.
E. Indicate the direction of current or flow to aid systematic elimination of possibilities without continuous cross-reference to schematics.
F. Provide "maintenance highways" to guide the technician through routine process. The following code has proven useful:
   (1) Black for line maintenance.
   (2) Green for shop maintenance.
   (3) Red for depot maintenance.
   (4) Other codes as necessary.



Instructions: Provisions should also be made for the following, when appropriate:

a. The weight of units over 45 lbs. should be prominently labeled.
b. Warning and caution labels should be provided as necessary.
c. Instruction plates should be provided to outline procedures not made obvious by design and to supply whatever information is necessary for troubleshooting and maintenance.
d. The presentation and/or recording of historical data where practicable, particularly to:
   (1) Display periodic readings at test points to allow development of trends where these are fundamental to maintenance decisions.
   (2) Allow recording of replacement dates or other data necessary to replenishing or preventive maintenance.

ACCESSIBILITY REQUIREMENTS:

Assemblies, modules, parts, etc., should be packaged and mounted so that:

a. The accessibility requirements discussed on p. 42 are satisfied.
b. The work space requirements discussed on p. 47 are satisfied.
c. Connector clearances discussed on p. 68 are satisfied.
d. Adequate tool access and wrenching space is provided around fasteners.
e. Adequate space is provided for use of test probes, soldering irons, and/or other service or test equipments.

f. Components to be serviced or repaired in position are at the most favorable working level i.e., between hip and shoulder height.
g. Maintenance required on a given unit or component can be performed:
   (1) With the unit or component in place, when possible.
   (2) Without disconnection, disassembly or removal of other items.

h. All replaceable items, particularly disposable modules, are removable:
   (1) Without removal or disassembly of other items or units.
   (2) By opening a minimum number of covers, cases, panels, etc.
   (3) Without hindrance from structural members or other parts.
   (4) Along a straight or slightly curved line, rather than through an angle or more devious course.

i. All large, heavy or awkward units are located so they:
   (1) May be slid out or pulled out rather than lifted out.
   (2) Do not prevent access to other removable items.
   (3) Are mounted on sliding drawers, racks, etc., wherever practicable.

j. When it is necessary to place one unit behind or under another, the unit requiring most frequent maintenance is most accessible.
k. All chassis are completely removable from the enclosure with minimum effort and disassembly.
l. Structural members of units, chassis or enclosures do not prevent access to removable units or their connectors of fasteners.

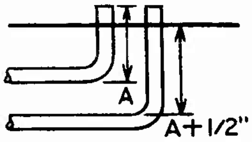
Clearance requirements:

In addition to the above, the location and packaging of units, items, parts, etc., should allow clearances, such that:

a. Unshielded electron tubes are 1.5 tube diameters apart.
b. Resistors and soldering points are separated by at least 3/16".
c. Solder connections, terminals, or bar conductors on terminal boards, relays, etc., are at least 1/4" apart.

d. Heat generating parts--electron tubes, resistors, dynamotors, etc.--are far enough from wires, cables, plastics and other heat sensitive materials to prevent deterioration of these materials under the specified operating conditions.

e. The distance between items requiring insertion is equal to the length of the longest related insert plus 1/2" (see at right).



HANDLING REQUIREMENTS:

Modules or other removable assemblies should be designed so that:

a. Removal and replacement requires minimal tools and equipment, and only common hand tools where practicable. (See "Tools," on p.118)
b. Rapid and easy removal and replacement can be accomplished by one man, two men, or handling equipment, in that order of preference.
c. Irregular, fragile or awkward extensions such as cables, wave guides, hoses, etc., are easily removable before the unit is handled; such protrusions are easily damaged and make handling difficult.
d. Handling and carrying are possible by one man:
   (1) Weight of removable units should be less than 45 lbs.
   (2) Difficult to reach units should weigh less than 25 lbs.
   (3) Units over 45 lbs. should be designed for two-man handling.
   (4) Hoist lugs should be provided for units over 90 lbs.
   (5) See "Handle requirements," on p.52.
   (6) See "Lifting capacity," on p.142.

PROTECTION AND SAFETY REQUIREMENTS:

The design, packaging and mounting of components, units, parts, etc., should provide the maximum protection for equipment and personnel against injury or damage.

Protection of personnel:

Units should be located, packaged, mounted and shielded so that access to them, adjacent items, or associated fasteners can be achieved without danger to personnel from electrical charge, heat, sharp edges or points, moving parts, chemical contamination, or other hazards.

Specifically, design, packaging and mounting should be such that:

a. "Protection and Safety requirements," on p.99 are satisfied.
b. Commonly worked on parts, fasteners, service or test points, etc., are not located near exposed terminals or moving parts.
c. Guards or shields are provided to prevent personnel from coming into contact with dangerous moving parts or injury potentials. (See "Covers and Cases," on p.82)
d. Ventilation holes in equipment are located and made small enough to prevent insertion of fingers, tools, etc., into hazardous areas. (1/2" holes will exclude fingers.)
e. Tool guides are provided to allow safe manipulation of points adjacent to high voltages or other hazards.
f. Capacitors, exhaust pipes or other parts which retain heat or electrical potential after the equipment is turned off are located or shielded so personnel cannot contact them accidentally.
g. Adequate clearance is provided, by recess or bumper, to protect toes or fingers from the dangers of dropped tow bars and similar items.
h. Safety devices are provided to prevent personnel from becoming entangled or struck by the starting cord or crank of manually started motors.

Protection of parts and equipment:

Parts, modules, and assemblies should be located, shielded or otherwise protected from accidental loss or damage.

a. Design covers, cases and shields to comply with requirements on p.82.
b. Protect lines and cables as discussed on p.78.
c. Locate floor-mounted items away from maintenance or other work paths.
d. Do not mount heat-conducting shields on or near plastic materials.
e. Design, ventilate or otherwise provide environmental control for heat sensitive items.

f. Use a fail-safe design wherever possible to prevent failures from causing secondary damage or failure of other items. (See "Fuses," on p.90.
g. Provide stiffening members as necessary for large, flat, unsupported or weak surfaces.
h. Mount switches, holders, meters, circuit breakers, and other such devices so they cannot be inadvertently actuated by the technician.

i. Employ shock-mounting ductile materials or flexible components wherever shock and vibration loads may be severe.
j. Attach small, removable pins, caps, covers, etc., by means of wire rope, wire cable, or retainer chains to prevent their loss or damage.
k. Design, package and mount movable equipment to insure maximum safety and stability when the unit is moved up an incline of up to 15°.

Vital, fragile, sensitive or easily damaged components should be located, arranged and shielded so they will not be:

a. Used for handholds, footholds, or rests.
b. Walked on or rolled over by wheeled traffic.
c. Near areas where heavy maintenance is performed.
d. Disturbed by vibration or movement of adjacent parts.
e. Damaged by flying particles, loose objects, or movements of personnel or tools during maintenance.

Tubes and similar plug-in components require good support.

a. Lack of sufficient support causes a great many failures.
b. Large or horizontally mounted tubes require a support member for the glass envelope; base clamping alone is seldom sufficient.
c. Tubes and plug-in items should be secured with clamps which:
   (1) Are positive holding but easily released for part replacement.
   (2) Are sturdy enough to retain the part in proper position under conditions of shock and vibration.

Shields for components such as tubes should be:

a. Of the correct size to provide good contact and support.
b. Of a tight fit to ensure good tube radiation and to provide good mechanical protection.

FASTENER REQUIREMENTS

DECISION FACTORS:

The design, selection or application of fasteners must take the following factors into consideration:

a. Stress and environmental factors the fasteners must withstand.
b. Work space, tool clearance and wrenching space around the fastener.
c. Types of tools required for operation of the fastener, as a function of fastener type, application and location.
d. Types and varieties of fasteners being used elsewhere in the system, or commonly used by the using agency.
e. The frequency with which the fasteners will be operated.
f. The time requirements of tasks involving operation of the fasteners.

Fasteners are available in a wide variety of types and sizes within each category, and new types are always appearing. The specification and/or application of fasteners should be preceded by a review of the varieties available. Fasteners should be selected and evaluated on the basis of durability, ease of operation, speed, and ease of replacement, and other requirements given below.

GENERAL FASTENER REQUIREMENTS:

Standardization of fasteners: To reduce storage of spare parts and to minimize the danger of damaging fasteners by use of the wrong tool or fastener for a given application:

a. Minimize the number of types and sizes of fasteners within the system.
   (1) Use only a few basic types and sizes which can be readily distinguished from each other.
   (2) Use the same type and size of fastener for a given application (for instance, all mounting bolts for a given type of item).
   (3) Make certain that screws, bolts and nuts of different thread size are of clearly different physical sizes; otherwise they may be interchanged.
   (4) Avoid requirements for special or close tolerance fasteners.

b. Minimize the number of differing torque requirements within the system.
   (1) Use only a few basic values.
   (2) Key these values to clearly differing types, sizes, or coded fasteners.
   (3) Plan for and provide clearance for wrenches or socket tools with variable torque settings, where precise torquing is required.

c. Minimize the number of tool types and sizes required for fastener operation.
   (1) Avoid requirements for special tools
   (2) Select fasteners for hand operation or operation by common hand tools. (See "Tools," on p.118)

Material of fasteners:

a. Fasteners should be of nonferrous (rust-resistant) material.
b. Corrosion-resistant steel or nickle-copper alloy may be used where strength is required.
c. Aluminum alloy should not be threaded into aluminum alloy parts.
d. Special or close tolerance fasteners should be avoided.
e. Tapped machine threads must have sufficient tensile strength to withstand maximum bolt or screw torque plus a safety margin to allow for wear.

Mounting of fasteners:

a. The replaceability of stripped, worn or damaged fasteners should be considered in design. Fasteners (studs) which are part of the housing should be avoided.

b. Fastener mounting holes or other tolerances should be large enough to allow "starting" of fasteners without perfect alignment.

c. Hinges, catches, latches, locks, and other quick disconnect devices should be attached by means of small bolts or screws, not rivets.

d. Bolts should be mounted with the head up so they will stay in position if the nut falls off.

e. Nuts and bolts (particularly those which are frequently operated or poorly accessible) should be mounted so they can be operated with one hand or one tool by:
   (1) Providing recesses to hold either the nut or bolt.
   (2) Semi-permanently attaching either the nut or bolt.
   (3) Using double nuts on terminal boards and similar applications.
   (4) Using nut plates, gang-channeling or floating nuts (see below).

Number of fasteners:

a. Minimize the number of fastener and fastener parts.

b. Maximize the use of hinges, catches, latches, and quick disconnect fasteners to reduce the number of fasteners required.

c. Use a few large fasteners rather than many small ones (except where many are necessary to maintain a fluid or air tight seal).

d. Use no more than four fasteners to mount a unit. A common fault is use of too many fasteners when a more rigid construction is preferred.

Location of fasteners: Locate fasteners so that they:

a. Can be operated without prior removal of other parts or units.

b. Can be operated with minimum interference from other structures.

c. Do not interfere with each other or other components.

d. Do not constitute a hazard to personnel, wires or hoses.

e. Are surrounded by adequate hand or tool clearance for easy operation. Requirements for two-hands or power tools for manipulation, breakaway, or removal of stuck fasteners should be considered.

Coding of fasteners:

a. All external fasteners which are manipulated during normal maintenance should provide strong color contrast with the color of the surface on which they appear.

b. All other external fasteners and assembly screws should be of the same color as the surface on which they appear.

c. The heads of "special" bolts and screws should be color- or stamp-coded to ensure that they are properly handled and are replaced by identical fasteners.

d. Only markings which designate the size, type or torque value of the fastener should be used; omit manufacturers' names or trademarks.

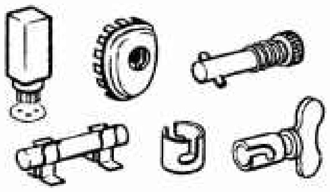
e. Fastener markings must be etched or embossed to withstand exposure to chemicals, fuels, LOX, weather or other operational conditions.

f. One fastener marking code should be used throughout the system; this code must be determined and standarized ahead of time, and it should conform to prevailing standard practices.

TYPES OF FASTENERS (In order of preference):

1. Quick disconnect devices.

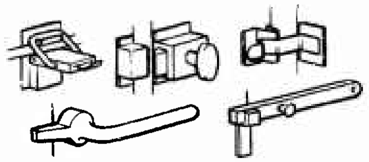
   These are fast and easy to use, require no tools, may be operated with one hand, and are very good for securing plug-in components, small components and covers. However, their holding power is low and they cannot be used where a smooth surface is required. Common types are pictured at right.



   Requirements:
   a. These fasteners must be carefully evaluated on the basis of type and application.
   b. These fasteners should be used wherever possible for components that must be frequently dismantled or removed.
   c. These devices must fasten and release easily, without the use of tools.
   d. They should fasten or unfasten in a maximum of one complete turn.
   e. It should be obvious when they are not correctly engaged.
   f. When many are used and misconnection is possible, the female section should be located, shaped, sized or coded so that only the correct male section may be attached. (See "Connectors," p.70)

2. Latches and catches.

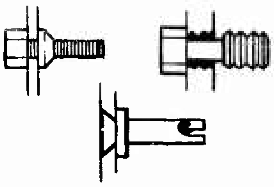
   These are very fast and easy to use, require no tools, have good holding power, and are especially good for large units, panels, covers and cases. They cannot be used where a smooth surface is required. Common types are pictured at right.



   Requirements:
   a. Provide long latch catches so that accidental springing is minimized.
   b. Locate and position latches and catches so they will not open accidentally under expectable operating conditions.
   c. Spring-load catches so they do not require positive locking, but lock on contact.
   d. Use a latch loop and locking action if positive locking is necessary to meet structural or stress requirements.
   e. If a handle is used in conjunction with the latch, locate the latch release on or near the handle so that only one hand is needed for operation.

3. Captive fasteners.

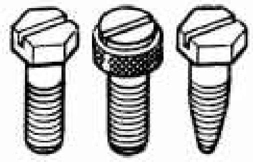
   These are slower and more difficult to use (depending upon type), and require use of common (usually) hand tools; but they stay in place, save the time spent handling and looking for bolts and screws, and screws, and require only one handed operation.



   Requirements:
   a. Use captive fasteners wherever "lost" screws, bolts or nuts might cause a malfunction or excessive maintenance time.
   b. Use only fasteners which may be operated by hand or common hand tool.
   c. Use only fasteners which may be easily replaced in case of damage.
   d. Provide self-locking, spring-loaded action on captive fasteners of the quarter-turn type.

4. Combination-head bolts and screws.

These should be used in preference to other screws or bolts simply because they may be operated more rapidly with either a wrench or a screwdriver; this allows use of the more convenient tool, and reduces the possibility of slot damage and stuck fasteners. In general, slotted, hexagonal heads are preferable to knurled and slotted heads.

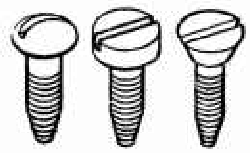


Requirements:

Otherwise the same as for bolts and screws.

5. Regular screws.

Round, square or flat-head screws require more time and are more subject to loss, slot damage, stripping and misapplication than the above; but they require less wrenching space, only one-handed action to operate, and do not involve a number of extra parts. Square-head screws are generally preferable to round or flat since they provide better tool contact, are less subject to slot damage, and may be removed with pliers.



Requirements:

a. The number of turns required to tighten or loosen a screw should be less than 10.
b. When tightened the screw must fully engage to a distance at least equal to its diameter.
c. Deep slots must be provided on screw heads to minimize slot damage.
d. Screws should be used only when screwdrivers may be used in a "straight-in" fashion; do not require use of offset screwdrivers.
e. If a screw must be operated blindly, provide a tool guide in the assembly.

f. Fine thread screws are recommended for pressurized units.
g. Countersunk screws should be used only where necessary to provide a smooth surface.
h. Round-head rather than flat-head screws should be used on panels less than 3/32 inch thick, to prevent screws from ripping through the panel.
i. Self-tapping screws should have one type of head and be of one size, where feasible, or a minimum number of sizes.

6. Bolts and nuts.

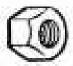
Bolts are usually slow and difficult to use; they require two-handed operation, access to both ends of the bolt, and often use of two tools. They also require precise movements in starting nuts, and have many loose parts to handle and lose (nuts, washers, etc.).

Bolt requirements:

a. Bolt length should not be more than required for a given purpose.
b. Bolt threads should be no finer than strength requirements dictate.
c. The number of turns to tighten a bolt should be less than 10.
d. When tightened, the bolt should extend a minimum of 2 threads beyond the nut.

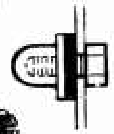
e. Hexagonal-head bolts should be used generally, and especially for high torque usages.
f. Left-hand threads should be used only when stress conditions require; and both bolts and nuts should be clearly identifiable by marking, shape or color. (see "Coding of Fasteners," p. 63)
g. Self-locking bolts (in tapped holes) should be used only when one surface must be smooth or is inaccessible and temperatures will be below 250° F.

Nut requirements:



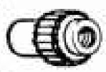
a. Regular hexagonal nuts are preferred, in a few easily distinguishable sizes.
b. Different sizes of nuts should be used for different thread requirements.

c. Wing or knurled nuts, which require no tools, should be used for low tension applications. Wing nuts are the easier to use.

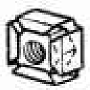


d. Self-sealing nuts should be used for fastening equipment to fluid tanks, to prevent leaking around fastener.

e. Lock nuts may be used for mounting light components; but they must withstand heat requirements, and cannot be used where fallen nuts could damage equipment.



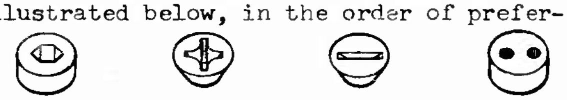
f. Clinch nuts should be incapable of rotating or moving with respect to the surface on which they are mounted.



g. Floating nuts should have an allowable shift of only plus or minus 1/16 inch.

7. Internal wrenching screws and bolts.

These allow higher torque, better tool grip, and less wrenching space. But they are easily damaged, are difficult to remove when damaged, and require special tools. Common types are illustrated below, in the order of preference:



Requirements:

a. The number of different sizes should be minimized to require only one, or as few as possible, special tools.
b. Slots should be deep, to minimize damage to the fasteners.
c. Design must allow and plan for the removal of damaged internal wrenching fasteners in terms of clearances, power outlets, etc.
d. Requirements are otherwise the same as for bolts and screws.

8. Rivets.

Permanent fasteners are very hard and slow to remove and replace; they should not be used on any part which may require removal. Wire stapling or metal stitching is generally preferable to rivets for maintenance purposes.

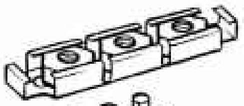
Requirements:

a. Rivets should not be used on latches, hinges or retainers.
b. Rivets should be of softer material than the pieces they fasten.
c. The heads of countersunk rivets should be larger than the thinnest of the pieces they fasten, to prevent them from ripping through.
d. Shear rivets do not expand to fill the hole, so holes must be drilled to close tolerances; and maintenance instructions should specify these tolerances and the sizes of plug guages and reamers to be used.

FASTENER ACCESSORIES:

Washer requirements:
a. Washers should fit tightly against the underside of the fastener head.
b. Washers should fit the shaft snugly, but should be easy to remove.
c. Split-ring lock washers should be used with static loads in excess of 2 oz.
d. Lock washers should be used with lock nuts, for maximum locking action.

Metallic inserts and blocks should be so secured that tightening of the screw or bolt will not loosen or move the insert or block.



Gang-channeling of nuts can save time in handling many nuts when they are in a straight line. Only channels should be used in which nuts can be replaced individually.

Nut-plates are heavy and expensive to replace when a hole is stripped; but they may be used when several bolts are to be fastened on one surface and alignment is no problem.

Cotter key and pin requirements:
a. Keys and pins should fit snugly, but should not require driving in or out.
b. Heads of cotter keys should be large, to facilitate removal and prevent the keys from slipping through.

Safety wire requirements:
a. Use safety wire only where self-locking fasteners or cotter pins are not adequate to withstand the expected vibration or stress.
b. Attach safety wire so it can be easily removed and replaced.

Retainer ring requirements:
a. Use only rings which may be removed and replaced easily when worn.
b. Use rings which hold with a positive snap action when possible.
c. Use spring tension to prevent loosening of twist-to-lock rings.

RETAINER CHAINS:
Use retainer chains or locking bars to:
a. Keep hatches or doors from opening too far and springing their hinges.
b. Turn doors or covers into useful shelves for the technician.
c. Prevent small covers, plates, or caps from being misplaced.
d. Secure small, special tools to the location in which they will be used.
e. Secure objects which might otherwise fall and cause personnel injury.

Retainer chain requirements:
a. Only link, sash, or woven-mesh type chains should be used. Bead-link chain is NOT recommended because it breaks more easily than other types.
b. Chains should be attached with screws or bolts; attachment should be strong and positive, but easily disconnected when required.
c. Eyelets should be provided at both ends of the chain for the attaching fasteners.
d. Chains should be no longer than necessary to fulfill their function.
e. Chains to filler caps should be attached externally rather than internally to facilitate replacement and prevent broken parts from damaging equipment.
f. Chains should NOT be used wherever they might interfere with moving parts.
g. Chain covers, where required to prevent chains from becoming tangled, should be flexible, durable, and easy to bend.

CONNECTOR REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Connector," here designates any fixture designed and intended to effect connection of lines or cables, as defined on p. 77.

Decisions regarding connectors must be compatible and coordinated with:
- a. Line and cable requirements as discussed on p. 77.
- b. Fastener requirements as discussed on p. 62.
- c. Mounting & packaging requirements discussed on p. 54-61.
- d. The environmental extremes to be withstood. (See "Environment," p. 126)
- e. The maintenance routines in which the connectors will be involved.
- f. The reliability requirements of the system; connectors are sources of unreliability and must be considered so in design.
- g. The reliability of components whose connection they effect; items low in reliability should be fastest and easiest to disconnect.

Connectors should be selected, designed and mounted to:
- a. Maximize the rapidity and ease of maintenance operations.
- b. Facilitate the removal and replacement of components and units.
- c. Minimize "set-up time" of test and service equipment.
- d. Ensure compatibility between prime and ground support or auxilliary systems.
- e. Minimize dangers to personnel and equipments from pressures, contents or voltages of lines during the release of connectors.
- f. Be operated by hand where possible, or with common hand tools. Requirements for special tools to effect connection, disconnection or removal of connectors should be avoided. (See "Tools," p. 118)

GENERAL REQUIREMENTS:

Standardization requirements:

Connectors should be so standardized as to satisfy the general concepts under "Standardization," on p. 120, and to:
- a. Minimize the number of different types of connectors.
- b. Minimize the likelihood of mismating, cross connection, or similar errors with connectors in installation or maintenance.
- c. Provide clearly different and physically non-interchangeable connectors for lines that differ in content--i.e., different voltages, oils, etc.
- d. Minimize the number of connectors used, consistent with:
  - (1) Accessibility and manipulation considerations.
  - (2) Intercabling requirements--i.e., the number of lines, routing of lines, electrical parameters, and types of connectors required.

Accessibility and location requirements:

Connectors should be located and mounted so they are accessible:
- a. According to the preferences and requirements discussed on p. 72.
- b. With a minimum of disassembly or removal of other equipments or items.
- c. In proportion to the frequency with which they must be operated; those used during pre-operating checks should be most accessible.

Connectors should be located so that:
- a. They can be easily reached for connection or disconnection.
- b. Easy visual access is provided to allow starting of connector threads or pins without potential damage to the connector.

c. Lines or cables with attached connectors are provided easy passage through walls, bulkheads, etc., to points of connection.
d. Spillage or leakage of fluids is minimized and, where it occurs, will not damage equipment.
e. Connectors are far enough apart or from other obstructions so they can be grasped firmly for connecting and disconnecting. In general, minimum separations are as follows: (See "Accesses," on p. 42-46)
   (1) 0.75" if only the bare fingers are required.
   (2) 1.25" if the bare hand or gloved fingers are to be used.
   (3) 2.00" if a gloved or mittened hand must be used.
   (4) As required for tool clearances. (See "Tools," on p. 118)

Mounting requirements:

Connectors should be mounted to their lines, cables, etc., so that:
a. They are easy to remove and replace.
b. Only common hand tools are required to remove and replace them.
c. The fasteners employed satisfy preferences and requirements discussed under "Fasteners," on p. 64.
d. Adequate tool clearances are provided around fasteners to facilitate rapid and easy operation.
e. Receptacles, terminal boards, terminal strips, stand-off insulators, etc., are mounted by bolts or screws and are capable of ready removal and replacement.

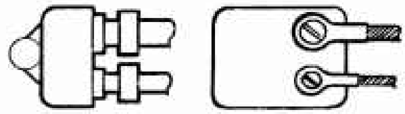
f. All external cables and interconnecting harnesses used to connect major units terminate on barrier type terminal boards.
g. The rear of panel-mounted connectors is available for test and service, except where potting or sealing prevents this.
h. Support is provided at the mounting point to reduce breakage and the effects of shock and vibration.
i. Where possible, the connector will part or disconnect under stress before the line breaks; connectors are easier to replace than lines.

Protection requirements:

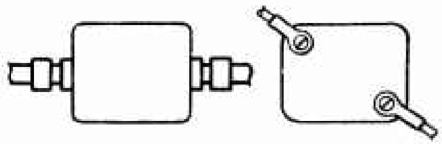
Connectors should be designed, located and protected as necessary to:
a. Minimize dangers to personnel and equipment from pressures, contents, or voltages of lines during release or handling of connectors.
b. Prevent damage to connectors, connector parts, or spare contacts from:
   (1) The collection of dust, dirt, moisture or other fluids.
   (2) Movements of personnel, shifting objects, opening doors, etc.
   (3) Excessive tightening or man-handling during operation.
   (4) Shorts or arcing as a result of foreign objects, erroneous connection, or handling after disconnection.

Protection should be provided by:
a. Recessing receptacles as necessary.
b. Recessing delicate connector parts (pins, keys, etc.) within the connector so they are not subject to harmful contact.
c. Providing protective caps, inserts, covers, cases, and shields as necessary. (See "Covers and Cases," on p. 82-86)
d. Ensuring that materials used for connector parts, particularly gaskets, seals, insulations, etc., are selected to withstand the extreme temperatures, pressures, stresses, and chemical characteristics of the operating environment or the fluids, etc., they must contain.

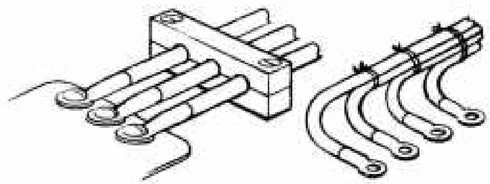
Connectors should be selected, designed, and installed to provide positive means of preventing mis-mating or cross connection. The following means should be considered:



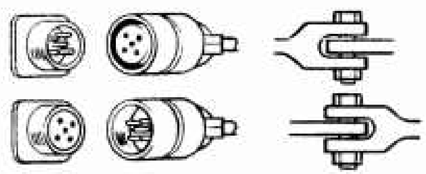
(1) Providing different sizes or different types of connectors on similar, adjacent leads.



(2) Arranging lines so that the distance from the connector to the correct point of attachment prevents mis-mating.

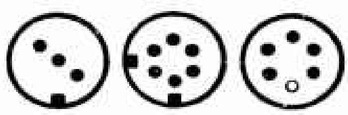


(3) Arranging lines or providing separation blocks or other mounts so the sequence of leads is obvious.

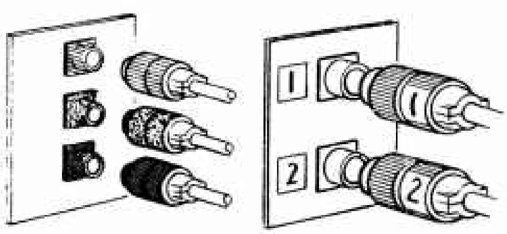


(4) Reversing adjacent identical connectors, so male and female ends alternate.

(5) Polarizing or using different sizes of prongs and prong receptacles. This is particularly useful to prevent mis-mating between lines of differing voltage values.



(6) Using different and mutually incompatible and irreversable arrangements of guide pins, keys or prongs.



(7) Clearly color coding or labeling connectors and their receptacles so confusion is minimized and mis-mating is unlikely.

Coding and labeling requirements:

Related requirements. Codes and labels used in conjunction with connectors should be consistent and/or compatible with:

a. The discussion under "Coding and Labeling," on p. 58.
b. The coding and labeling of lines and cables.
c. Codings used to prevent mis-mating and cross connection. (See p. 70)
d. Other codings used in the system.
e. MIL-STD-101, AFBM Exhibit 58-20, and other references specified by or acceptable to the user. (Ref. 7, 19)

Provisions: Connectors and associated parts and wiring should be coded and labeled as necessary to:

a. Facilitate reference to them in the job instructions.
b. Identify replaceable items and parts to allow re-ordering.
c. Expedite and facilitate maintenance and troubleshooting procedures.
d. Reflect the sequentiality of routine procedures and test procedures.
e. Ensure proper connection and prevent errors in connection.
f. Provide continuity of reference throughout the system.
g. Provide adequate warnings or cautions relevant to connector operation.

Identification: Codes and labels should be provided as necessary to ensure that:

a. Each plug is clearly identified with its receptacle(s).
b. Each wire is clearly identified with its terminal post or pin.
c. Test points are clearly identified by a unique mark or symbol.
d. Non-interchangeable connectors are clearly distinguishable.
e. The manner of connection or disconnection is clear.
f. Plugs and receptacles have painted strips, arrows, or other indication to show orientation of aligning pins for proper insertion.
g. Terminal strips and boards are marked in a permanent manner so as to identify individual terminals and facilitate connector replacement.
h. Power receptacles for primary, secondary or utility systems are clearly labeled to prevent personnel injury or equipment damage.
i. Cable connectors are labeled with the:
   (1) Type of current and voltage values.
   (2) Designation of the current source--i.e., line, battery, etc.

Location. Codes and labels of connectors and associated items should be so located that:

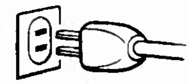
a. They are maximally visible under operational maintenance conditions.
b. They are visible in both connected and disconnected conditions.
c. Connectors can be identified without having to be disconnected.
d. Labels are in a consistent position relative to their associated pins, terminals, receptacles, etc.
e. If room is unavailable for complete labels, simple symbols are provided and are explained on a nearby plate and/or in the job instructions.

Codes and labels should be located (in order of preference):

1. Directly on the plug, wire, receptacle, etc.
2. On plates permanently affixed to the plug, receptacle, etc.
3. On the immediately adjacent surface, panel or chassis.
4. On or near the access opening, if the connector is recessed.
5. On tags or tapes attached to the wire, plug, etc.

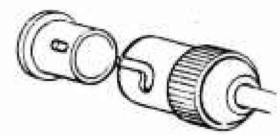
TYPES OF CONNECTORS (In order of preference):

1. Plug-in connectors.
These are the fastest and easiest to use--e.g., simply push in or pull out, but they have low holding power.



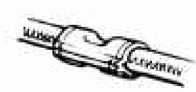
Requirements:
- a. Do not use where stresses or pressures will overcome holding power.
- b. Do not use where holding power is such that lines are likely to be damaged or connectors loosened by the pulling required to disconnect.
- c. Use where possible for all connections that will not be seriously stressed and particularly for those that must be frequently disconnected.

2. Quick-disconnect devices.
These are very fast and easy to use. They exist in a variety of forms and include any type of connector that can be released by snap action, twisting up to a full turn, triggering a latch or spring device, or removing an external pin.

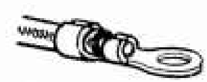


Requirements: Quick-disconnect devices should be:
- a. Designed for hand operation, while catches, pins, etc. should be designed for operation with gloved hands.
- b. Designed to prevent loosening which allows leakage or overheating from pressures or voltages involved.
- c. Provided with self-locking catches, as necessary, to prevent loosening, resist stress, and ensure secure connection.
- d. Used for all connections of:
  - (1) Auxiliary, test or support equipment to other major units.
  - (2) Units which require frequent disconnection or replacement.
  - (3) Units which require replacement within critical readiness times.

3. Lugs and crimp-on devices.
These are most useful to connect or splice single wires. Both can be used, and are preferable to soldering, at elevated temperatures.

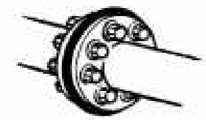


Requirements:
- a. Lugs must be compatible with the "Terminal post requirements," on p. 74.
- b. Where lugs and crimp-on devices are used, slack should be provided for at least 6 replacements of those devices which must be cut off.
- c. Lugs and crimp-on devices should clamp the insulation as well as the conductor, to provide support for the line and preclude flexing of the conductor against the end of the connector.



- d. "U-lugs" should be used rather than "eye-lugs." The former:
  - (1) Are easier and faster to connect and disconnect.
  - (2) Do not require complete removal of the connecting fastener.
  - (3) Are more likely to disconnect rather than allow the line to break under extreme stress.

4. Bolt or screw assemblies:

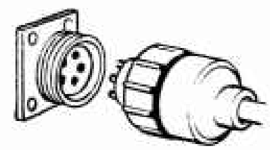


These provide very secure connection, but also require time consuming handling and operation of bolts or screws. They are particularly useful for connecting large or high pressure lines.

Requirements. Bolt or screw connector assemblies must:

a. Satisfy the preferences and requirements under "Fasteners," on p. 64.
b. Ensure adequate work and tool clearances about these fasteners.
c. Employ the minimum possible number of separate parts.
d. Satisfy "Gasket and seal requirements," on p. 76.

5. Threaded connectors:



These provide very secure connection, particularly when locked into place by set screws, retainers or safety wires. They require more time to operate, depending upon the ease of operation, number of turns required, and types of tools required.

Requirements. Threaded connectors should:

a. Require as few turns as are consistent with holding requirements.
b. Be operable by hand when used for electrical connection.
c. Require only common hand tools or special tools which are immediately accessible.
d. Be so designed that the line need not be backed-off to effect connection or disconnection, especially in the case of rigid lines.
e. Be designed and arranged to reduce the danger of loosening other connectors while working on one. This is a major problem with threaded fasteners on continuous pipe or tube systems.
f. Be designed so that aligning guides and connector pins are easy to engage and start sufficiently to ensure accurate engagement before the threaded section makes contact.

6. Soldering, brazing, or welding:

Such methods provide the securest connection, and are often the most efficient way of securing small connection points or maintaining hermetic seals. But such connections require considerable maintenance time for connection or disconnection.

Requirements:

a. Soldering should satisfy the "Terminal post requirements," on p. 74.
b. Welding and brazing should be used only for connections that are very unlikely to require disconnection.
c. These methods should never be used to effect connection of lines or assemblies that may require disconnection by line maintenance personnel.

7. Wire-wrapping or pig-tailing:

Such methods are only useful for electrical connections and should be avoided, because they require more maintenance time, damage conductors, and do not provide reliable contact.

ELECTRICAL CONNECTOR REQUIREMENTS:

Contact requirements:

Inadequate contact is a constant source of intermittent faults, and can be largely prevented by:

a. Using moisture proof connectors wherever possible.
b. Keeping insertion forces low, to minimize the possibility of damaging contact surfaces on connector parts.
c. Avoiding contacts which depend upon wires, lugs, terminals, etc. clamped between a metallic member and an insulation material. All such contacts should be clamped between metal members.

d. Ensuring that both ends of static discharge lines and ground wires are securely fastened. Alligator clips are preferred for temporary grounding or testing because they are fast and easy to use, but should not be used for permanent grounding where they may be inadvertently detached.

e. Using spring contacts which are:
   (1) Relatively long to avoid concentrating stress and permit contact surfaces to wipe each other clean as contact is made.
   (2) Made of beryllium copper where contact is to be frequently stressed. Copper is adequate for most other purposes.
   (3) Not stamped from flat metal, for these tend to resume the flat shape after a number of flexings.

f. Plating contact surfaces with non-tarnishing materials, such as:
   (1) Gold, which is perfect plating material, but very costly.
   (2) Cadium, which is satisfactory for most purposes.
   (3) Silver, which may be used wherever its tendency to migrate in humid environments does not interfere with circuit operation.
   (4) Other materials acceptable to the user.

Terminal post requirements:

Loose or poorly arranged terminal posts require about 3 times as long for soldering or connection than adequately secured posts. These deficiencies can be largely overcome by:

Locating, constructing, and arranging the posts so that:

a. They are accessible, (See "Accessibility requirements," on p. 68)
b. A maximum of 3 wires will be attached to a single post.
c. Good electrical contact is assured.
d. Posts will not loosen, rotate or break with repeated usage.
e. Wires can be repeatedly removed and replaced, disconnected, and/or soldered without damaging or loosening the posts.
f. Adequate hand and tool clearances are provided for connection and disconnection.
g. Posts are far enough apart so work (particularly soldering) on one terminal does not damage neighboring connections, insulations or other parts.

Solder type posts should, in addition, be designed and mounted so that:

a. They are completely plated with tin or silver.
b. They are notched or provided with other means for mechanically securing the wire prior to soldering.

c. The free end of the wire sticks out of the solder and thus can be easily grasped with pliers to facilitate disconnection.
d. Supports are provided, where stranded copper wire is to be soldered, to prevent flexing where the strands are tinned together.

Plug requirements:

Electrical plugs should be designed, installed and mounted so that:

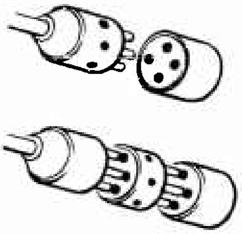
a. It is impossible to insert the wrong plug into a receptacle.
b. It is impossible to insert a plug the wrong way in its own receptacle.
c. Multi-contact plugs are used wherever possible, to reduce the number of plugs and the number of maintenance operations required.
d. Plugs "plug-in" or require no more than one complete turn to effect secure connection, especially for connection of auxiliary or test equipment.
e. Wiring is routed through the plugs and receptacles so disconnection does not expose hot leads.
f. All "hot" contacts are socket contacts--i.e., receptacles are "hot," and plugs are "cold" when disconnected.
g. Plugs are self-locking, or use safety catches rather than require safety wiring.
h. Safety wiring is provided for all transmission cable connectors which are inaccessible during flight.
i. Right-angle plugs are used to avoid the need to bend wires more sharply than a bending radius of 6 times the wire diameter, and to facilitate replacement of wires so routed.

Alignment keys or pins should be designed and located with the plug so that:

a. They extend beyond electrical pins to protect the pins from damage from poor alignment.
b. They are not in symmetrical arrangements that allow plugs to be inserted incorrectly.
c. All alignment pins for a given plug (as for test equipment) or series of plugs are oriented in the same direction. If this conflicts with mismating requirements, orientation of the pins should differ in a consistent and systematic manner, in order to be maximally convenient to the technician.

Test points should be provided:

a. In plugs where such testing is required and other special test points have not been provided.
b. In adaptors to be inserted between the plug and receptacle, if it is not feasible to provide test points in the plug and other adequate test points are unavailable.



Such test points must be adequately:

a. Protected by elastometers, seals, covers, or other means.
b. Accessible in terms of clearances and relationship to the normal setting of the plug or adaptor.
c. Coded and labeled to be clearly visible, and identifiable in test procedures.

FLUID AND GAS CONNECTOR REQUIREMENTS:

Related requirements:

Connectors for pipes, tubing, hoses, etc., should satisfy considerations under:

a. The "General requirements," above.
b. "Lines and Cables," on p. 77-81.
c. "Fluid and gas line requirements," on p. 79.
d. "Drain plug requirements," on p. 92.

Location requirements:

Connectors for pipes, tubing, hoses, etc. should be located and installed so that:

a. Backing-off of the line or removal of other components is not required to effect disconnection, or removal of related items.
b. Draining, filling, or other maintenance involving the connectors can be accomplished without jacking up the equipment.
c. Leakage tests can be performed easily and without endangering the technician. Tests should be planned so the technician does not have to insert his head into areas of extreme noise, vibration or other danger while the equipment is running. (See "Environment," p. 126)

Gasket and seal requirements:

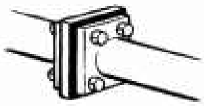
Gaskets and seals used in the connection of fluid or gas lines should be selected and installed to:

a. Be replaceable or have renewable wearing surfaces, rather than require throw-away of the connector when the seal is damaged or worn.
b. Be easily replaceable without removal of other connector parts or disassembly of other equipment.
c. Be identifiable with part numbers so they can be easily ordered and handled logistically; the job instructions should specify the life of seals and gaskets and recommend when they should be changed.

d. Contain or provide features, where required, which:
   (1) Permit lubricant escape under conditions of high pressures.
   (2) Prevent leakage of fluid when disconnect is made.
   (3) Prevent air from entering disconnected lines, where such air would create maintenance problems, as in hydraulic lines.
   (4) Allow tightening to offset shrinkage, particularly of rubber seals and gaskets.

Use gaskets and seals which:

a. Are visible externally after they are installed, to reduce the common failure to replace seals during assembly or repair (see at right).



b. Do not protrude or extrude beyond the coupling. Protruding seals are chipped and shredded by vibration or contact and the damage spreads internally to destroy sealing power and deposit pieces in the line. Tapered nylon or teflon washers of appropriate size can be employed to prevent extrusion.

LINES AND CABLES

DECISION FACTORS:

Explanation: The term, "lines," here designates any single length of pipe, hose, wire, or tubing.
The term, "cable," here designates a number of lines which are bound together within a single, permanent sheath.

Cables and lines should be selected, designed, bound, routed, and installed to:
- a. Preclude wearout, breakage or damage of lines and cables.
- b. Facilitate logical and efficient divisions of maintenance responsibilities.
- c. Provide for and facilitate rapid and easy:
  - (1) Troubleshooting, testing, checking and isolation of malfunctions.
  - (2) Tracing, removal, repair, and replacement of lines and cables.
  - (3) Removal and replacement of other items and components.
  - (4) Connection and disconnection of lines and cables.

Decisions regarding lines and cables should be compatible and coordinated with:
- a. Connector requirements as discussed on p. 68-76.
- b. Fastener requirements as discussed on p. 62-67.
- c. Access requirements as discussed on p. 42-46.
- d. The environmental extremes to be withstood. (See "Environment," p. 126)

GENERAL REQUIREMENTS:

Standardization requirements:
Lines and cables should be so standardized as to satisfy the general concepts under "Standardization," on p. 120 , and to minimize the number of:
- a. Types and varieties of lines and cables.
- b. Different lengths of lines and cables of the same type.
- c. Related connectors, fittings, fixtures and features.

Accessibility requirements:
Lines and cables should be routed and mounted so they are accessible:
- a. According to the preferences and requirements discussed on p. 42.
- b. With a minimum of disassembly or removal of other equipment or items.
- c. Particularly at points of connection, mounting, splicing or testing.
- d. For complete removal and replacement in case of damage; provide accesses and clearances for such removal and replacement.

Routing requirements:
- a. Route lines over the shortest runs possible consistent with lead requirements, mounting requirements, and other requirements.
- b. Route high-pressure or high-voltage lines and cables away from sensitive equipment, high temperature sources, work areas, and fasteners, controls, accesses, or other areas where personnel may work or reach.
- c. Do not route lines or cables through remote switches or valves which may be inadvertently used while the equipment is being worked on; where such controls are required, provide safety controls near the work point.
- d. Route lines and cables so they will NOT be:
  - (1) Used for hand-holds of foot-steps.
  - (2) Bent or twisted sharply or repeatedly, for any reason.
  - (3) Walked on or rolled over by wheeled traffic.
  - (4) Pinched or stressed by cargo, loose objects, doors, lids or covers sliding drawers or roll-out racks.

Mounting requirements:

Lines and cables should be mounted so that:

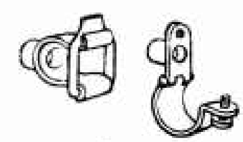
a. They will be out of the way of other maintenance operations.
b. They will not chafe or flex excessively under expectable conditions.
c. They are protected from metal edges by suitable grommets or pads.
d. They are securely anchored to the chassis by mounting plates or clamps, as discussed below. Twine or tape should not be used for this purpose.
e. They are not terminated or mounted on the front of cabinets or control-display surfaces (test cables are the exception).
f. Those associated with receptacles mounted on control-display surfaces will not interfere with or obstruct controls, displays, or other operations and procedures.
g. Entrance plates are provided where required for structural or other reasons; these should be so secured that no loose parts can interfere with operation of the enclosed equipment. (See "Fasteners," p. 67)

Clamp requirements:

Clamps or mounting plates used to mount lines and cables should:

a. Make a snug fit without deforming or crimping the line or cable.
b. Be spaced not more than 24 inches apart.
c. Be put at both ends of bends where bending radius is 3 inches or less.
d. Be asbestos lined if the line is likely to become extremely hot.
e. Be non-conductive or suitably insulated if securing a conductor.
f. Require only one-handed operation, by hand or with common hand tools.

g. Be of a quick release, hinged or spring type if the line or cable must be frequently removed. Hinged clamps are preferred; they support the weight of the line during maintenance, freeing the technician's hands for other tasks (see at right).

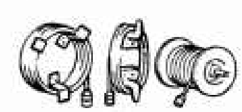


h. For overhead mounting, be of a spring clamp type with a hinged locking latch over the open side of the clamp to prevent accidents (see at right).

Storage and handling requirements:

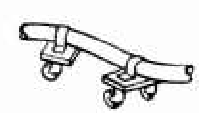
Adequate handling and storing provisions must be made for lines and cables of the extension type, or which are part of ground power, service and test equipment. The following are illustrative:

a. Provide adequate, covered storage space in ground support equipment for storing lines and cables.
b. Provide suitable racks, hooks, or cable winders within the storage space to hold lines and cables in a convenient and accessible manner (see at right).



c. Provide reels or reel carts for the handling of large, heavy, or very long lines and cables. Use automatic or powered tensioning or rewinding reels where possible to prevent damage and kinking, and to maximize ease of handling (see at right).

d. Provide wheels or other mobile supports for extra large lines and cables that must be frequently moved, (see at right).



FUNLD AND GAS LINE REQUIREMENTS:

Routing requirements:

Lines for fluids and gases should be designed and routed to prevent:

a. Misconnection during servicing or maintenance operations.
   (1) Standardize fittings so it is physically impossible to interchange lines that differ in content.
   (2) Employ arrangement, size, shape, and color coding as necessary to prevent interchange of adjacent lines. (See "Connectors," p. 71)
   (3) Identify all fluid carrying lines by color bands as specified in AFBM Exhibit 58-20. (Ref. 19)
b. Spraying or draining on personnel or equipment during disconnections.
   (1) Locate connections away from work areas and sensitive components.
   (2) Provide shielding for sensitive components where required.
   (3) Provide drains and bleed fittings to allow drainage or reduction of pressure prior to disconnection.
   (4) Provide high visibility warning signs at disconnect areas or where pressures or the content of lines could injure personnel.
c. Drainage problems. (See "Drain point requirements," p. 92)
   (1) Design so lines can be completely emptied when required.
   (2) Avoid low points or dips in lines that are difficult to drain.
   (3) Make bends, where possible, in the horizontal rather than the vertical plane, to avoid fluid traps.
   (4) Provide low point drains where required to drain such traps.

Mounting and installation requirements:

a. Install rigid lines with fittings that do not require the line to be backed-off for disconnection. Backing-off requires the release of many mounts and consumes considerable time. (See "Connectors," p. 68-76)
b. Use tubing in preference to rigid lines, as it allows more flexibility in handling, can be backed-off easily, and is easier to thread through equipment when replacement is necessary.
c. Use flexible hose, rather than pipes or tubing, where minimum space is available for removal, replacement, or handling of lines. It can be backed-off or pushed aside for access to other components.
d. Provide adequate supports for lines which run from external service or test equipment, or where extensions will be afixed for other purposes. Such supports must withstand:
   (1) The initial surges of pressure through the line.
   (2) The weight of the external extensions.
   (3) The rigors of handling and repeated connection and disconnection.
e. Install and mount lines in such a way as to preclude kinking:
   (1) Employ sufficient mounts and supports to prevent kinking.
   (2) Employ quick-disconnect fittings to reduce man-handling of lines during connection or disconnection.
   (3) Eliminate work space restrictions around mounts and connections that may cause the technician to bend the line in installation, disconnection or removal.

ELECTRICAL WIRE AND CABLE REQUIREMENTS:

Cable, harness, and lead requirements:

The layout and routing of cables and wire should be predetermined and made as simple and functionally logical as possible, by:

a. Combining conductors into cable wherever practical.
b. Combining conductors into harnesses wherever cables are not used.
c. Minimizing, in turn, the number of wires, harnesses, and cables.
d. Segregating conductors into and within cables or harnesses according to their functions and relationships to replaceable equipments.
e. Using preformed cables wherever possible to minimize wiring errors and to allow more flexible and efficient assembly methods; provide spare leads in these cables to allow for growth and to speed wiring time.

Harnesses should:

a. Be designed, fabricated, and installed as units.
b. Be held securely with lacing twine or other means acceptable to the user.
c. Keep the individual conductors essentially parallel, so they do not intertwine, though twisted pairs may be used when required.

Lead lengths should be as short as is consistent with the task at hand, but sufficiently long to permit:

a. Easy connection and disconnection, with enough slack to back the wire away from the point of attachment to facilitate removal of the unit.
b. Sufficient slack for at least two (preferably 6) replacements of terminal fittings, electrical considerations permitting.
c. Movements of moving parts to which they may be attached (doors, covers, etc.) without undue stress or bending.
d. Connection, disconnection or movement without requiring a bending radius of less than 6 times the diameter of the lead.
e. Movement of units which are difficult to handle in their mounted position to a more convenient position for connection or disconnection.

Extension cables should be planned, designed, and provided as necessary to:

a. Increase the efficiency and ease of maintenance.
b. Avoid removal of assemblies or components for testing.
c. Allow each functioning unit to be checked in a convenient place.
d. Allow support equipment to be parked or set in a convenient place.
e. Serve as many related functions as possible, yet avoid the possibility of misuse or misconnection. (See "Connectors," p. 69-70)

Mounting requirements:

The mounting of electrical wires, harnesses and cables should:

a. Satisfy the "General requirements," listed above.
b. Ensure that lightly insulated wires clear parts normally at ground potential by at least 0.75 inches under operating conditions.
c. Employ raceways, stuffing tubes, conduit, junction boxes, and insulation as necessary to obtain the required degree of protection, security of mounting, and ease of maintenance.
d. Ensure that adequate accessibility is provided to raceways, stuffing tubes, etc. (See "General requirements," p. 77-78)
e. Allow checking of the signal flow through each conductor, by:
   (1) Arrangement, location and mounting of leads.
   (2) Providing test points where leads are unavailable for testing.
   (3) Providing test points in connectors. (See "Connectors," p. 75)

Leads should be mounted so they:

a. Do not bear the weight of the cable, harness or other components.
b. Are provided with support at splices and points of connection.
c. Are "fanned out" to provide adequate clearance for the technician's hand and/or any tool required for checking or connection.
d. Are oriented, where possible, in such a manner as to prevent erroneous connection or "crossing." (See "Connectors," p. 70)
e. Do not allow flexing at weak areas--e.g., at splices, solder points, or where the conductor is bare or crimped, or strands are tinned together.

Flexibility requirements:

Cables or leads to moving parts, doors, covers, etc., should be provided suitable slack and protection so they:

a. Allow movement of the part (door, etc.) without their disconnection.
b. Fold out of the way automatically when the part is moved.
c. Do not chafe or break under the repeated flexing required.
d. Are not pinched or otherwise damaged by movement of the part.
e. Satisfy requirements discussed under "Drawers and Racks," p. 51.

Protection requirements:

Protect wire and cable insulation from:

a. Termite destruction, by coating them with compounds of creosote, DDT, antimony or other mixtures acceptable to the user.
b. Fluids, such as grease, oil, fuel, hydraulic fluid, solvents, etc., by:
   (1) Routing them over, rather than under, pipes or fluid containers.
   (2) Routing them away from areas where fluids are likely to drip.
   (3) Suspending them out of areas where fluids are likely to accumulate (e.g., in pans and trenches, under floorboards, etc.).
   (4) Providing water-proof and/or oil-proof insulation, shielding, conduit, etc., as necessary.

Material considerations:

a. Clear plastic insulation allows rapid detection of internal breaks.
b. When polyvinyl wire is used, care should be taken so there will be no cold flow of the insulation due to tightness of lacing or mounting.
c. Neoprene-covered rather than aluminum sheathed cable should be used in areas where intense vibration or corrosive substances may cause failures.
d. High-temperature wire should be used when wires are routed near ducts carrying pressures over 50 psi. and/or temperatures above 200°C (392°F).
e. Metallic shielding unprotected by outer insulation should be secured to prevent the shielding from contacting exposed terminals or conductors.

Coding and labeling requirements:

Conductors should be coded and labeled:

a. In accordance with the provisions under "Coding and Labeling," p. 58.
b. In accordance with the provisions under "Connectors," p. 71.
c. In accordance with ARDC Manual 80-5, engineering standards, and/or other standards acceptable to the user. (Ref. 24)
d. So that each conductor is identifiable throughout the length of each cable or harness, and is uniquely identifiable wherever tracing will be required.
e. So the codes and labels used correspond with those of connector designations, test point designations, and the function of the conductor.

COVER, CASE AND SHIELD REQUIREMENTS

DECISION FACTORS:

Covers, cases and shields should be provided as necessary to:

a. Maintain the degree of enclosure required by structural, operational, or environmental protection or control, or other requirements.
b. Divide enclosures into sections which differ by virtue of temperature or ventilation control, types of cleaning methods to be used, etc.
c. Protect personnel from coming into contact with dangerous electrical or mechanical parts.
d. Protect moving parts, fuels, lubricants, etc., from dust, dirt, moisture, chips, grit or splatter.
e. Protect delicate or sensitive equipment from damage by movements of personnel, shifting of cargo of loose objects, or actions involved in the installation and maintenance of nearby assemblies.

In addition to the criteria implicit above, covers, cases, and shields should be designed and evaluated in terms of the degree to which they contribute to, or detract, from the speed and ease with which required maintenance can be performed. Their value in this respect largely depends upon:

a. The manner in which they are fastened. (See "Fasteners," p. 62-67)
b. Their size, weight, and ease of handling. (See "Handling," p. 60)
c. Provisions for handles or tool grips. (See "Handles," p. 52)
d. The work space and clearance around them. (See "Work Space," p. 47-50)
e. The degree to which the requirements listed below are satisfied.
f. The frequency with which they must be opened or removed, in terms of the reliability and maintenance requirements of the enclosed components.

GENERAL REQUIREMENTS:

Size requirements:

The cover, case of shield should:

a. Be light weight, if possible, but be whatever size is necessary to accomplish the degree of enclosure and allow the degree of accessibility required.
b. Be openable, removable and transportable by one hand, one man, or, at most, two men, in that order of preference.
c. Be provided with lifting eyes and planned for crane handling if more than 150 pounds.
d. Be provided with handles or tool grips if heavy or difficult to open or handle. (See "Handles," p. 52)
e. Allow sufficient clearance around enclosed components to minimize damage to these components and to avoid requirements for extremely fine or careful positioning and handling.
f. Be designed and located so that bulkheads, brackets, or other units will not interfere with operation of the cover or case and so the cover or case, when opened, will not interfere with other maintenance operations.

Shape requirements:

The shape of the cover, case or shield should:

a. Be whatever is necessary to accomplish the degree of enclosure, allow the degree of accessibility, and provide the clearances required.
b. Make obvious, if possible, the manner in which the item must be positioned or mounted.
c. Make obvious, if possible, the orientation of enclosed delicate components, to minimize damage to these during removal of the item.

d. Be free from sharp edges or protrusions which could injure personnel or damage lines and wires.
e. Be free of indentations or settling areas on top surfaces, to reduce rust, corrosion, and the accumulation of dirt and grease.

Mounting requirements:

Design, locate and mount covers, cases and shields so they:

a. Do not bear any part of the structural load. It should not be necessary to support, download, or disassemble any equipment to remove the item.
b. Are completely removable and replaceable in case of damage. Irregular extensions and accessories should be readily removable.
c. Can be opened or removed as necessary when the equipment system is completely assembled and auxiliary equipment has been installed.
d. Do not cause the equipment to become unbalanced when opened. Provide props, retainers, or other support where required to prevent this.
e. Do not obsure or interfere with controls, displays, test points, or connections related to work within the access or enclosure, when in the open position.
f. Are provided with adequate stops and retainers to prevent them from swinging into or being dropped on fragile equipment or personnel.
g. Are provided with locking devices or retainer bars to lock them in the open position if they might otherwise fall or shut and cause damage, injury or inconvenience. This is particularly necessary for doors, covers and shields which may be used in high winds.

Fastener requirements:

Select, apply, and mount fasteners for covers, cases and shields so that:

a. They optimally satisfy the preferences, requirements and standardization requirements under "Fasteners," on p. 62-67.
b. Maximum use is made of hinges and latches or catches to minimize the number of fasteners and requirements for handling and stowing covers and cases.
c. Fasteners for a given item or identical items are interchangeable--i.e., are the same type, size, diameter and pitch of thread.
d. Fasteners align themselves with their retaining catches, nuts, blocks, or inserts without sticking and without damage to their threads or latches.
f. The cover or case will not open or loosen accidentally under whatever stress, vibration or other conditions are expectable.
g. It is obvious when a cover or case is not in place or securely fastened. Where possible spring load fasteners so they stand out or the cover itself stays ajar when not secure.

Labeling requirements:

Provide labels and markings on covers and cases which:

a. Provide opening, removal or positioning instructions, if methods for accomplishing these are not obvious from the design.
b. Provide stock references so that covers, cases and shields can be replaced when damaged.
c. Adequately reveal the functions of units behind the enclosure and/or the functions which are to be performed through the access, such as "Battery," "Fuel Pump," "Oil Here," etc.
d. Adequately warn against dangers or hazards involved in removing the cover or case or working within the enclosure.
e. Provide the proper orientation or connection of units, service equipments etc., to go through the opening, if this is not clear or visible.

f. Do NOT provide instructions, such as preventive maintenance instructions, which are subject to revision or change.
g. Do NOT provide instructions which will be required but will not be visible when the cover, door or case is open; place such instructions in a visible location on the structure behind or to the side of the access.

MATERIALS FOR COVERS AND CASES:

The advantages and disadvantages of common materials from a maintainability viewpoint are discussed below:

Plastics are non-conductive, low cost, light weight, resilient, easily scratched, easily damaged by acids, solvents, fuels, and oils, and are not very strong. Clear plastic allows visual access to enclosed areas, but transparency decreases with age, and use must carefully consider lighting and glare problems.

Glass is non-conductive, expensive, heavy, and subject to breakage; but it is stronger, resistant to scratches and nearly all fluids; and it maintains transparency. Lighting and glare problems must be carefully considered when using glass to provide for visual access. Only glare-proof and shatterproof glass should be used for windows. Window glass should be secured by means of clips, snap rings, or other mechanical devices. Do not use cement alone to secure window glass.

Wire or metal screen is particularly useful to permit visual access to and circulation around equipment while protecting personnel from injurious contacts. It does not permit environmental protection or control, but is more durable.

Fabrics such as canvas, soft plastics, etc., usually require a great many fasteners to effect the desired degree of enclosure, but should be considered for specific applications, particularly for storage covers, temporary shields, etc. They are easily stored and handled.

Solid metal provides the greatest strength and degree of protection, but is conductive, prohibits visual access, and is usually heavier and more expensive.

Other materials such as wood, fiberglass, fiberboard, etc., have in general the same advantages as metal, and are non-conductive and usually lighter, but are also less durable and more subject to weathering.

CASE REQUIREMENTS:

In general, cases should be selected, designed, and mounted so that:

a. They are lifted off units, rather than units lifted out of cases, particularly when heavy units are involved.
b. They are sufficiently larger than the units they cover to expedite removal and replacement and prevent damage to wires or other components during removal or replacement.
c. Guidepins and tracks are provided as necessary to help align the case, prevent it from cocking or binding, and prevent damage to delicate or sensitive components during movement of the case.
d. Access is provided, where feasible, to frequently used adjustment, test, or service points, so that the case need not be removed in routine maintenance.
e. All maintenance-significant aspects and portions of the unit are fully exposed when the case is removed.

f. Adequate mounting or locking devices are provided and the unit is secure while the case is being moved, particularly if the unit is to be detached from the bottom of the case.

g. Rubber stripping or other sealing material is selected and mounted so it will not be damaged or jam when the case is moved.

SHIELD REQUIREMENTS:

Shields and protective covers should be provided as necessary to close openings and otherwise protect equipment that is not in use against the weather, sand, dust, moisture, exhaust, fumes, welding splatter, etc. The design of such shields should:

a. Employ light-weight material.
b. Allow rapid and easy installation, removal, transportation, and storage.
c. Provide handles and tool grips as necessary to facilitate handling.
d. Minimize the possibility of damage to the equipment during installation, removal or other operations related to the shield.
e. Avoid or minimize permanent fixtures on the equipment as a consequence of the shield--e.g., mounts, safety features, etc.
f. Permit performance of maintenance functions without removal of the shield; for instance, radial engine shields should permit cranking while the shield is in position.
g. Be mounted in a manner that does not interfere with the operating characteristics of the equipment; for instance, aircraft engine shields should fit into or around the engine or orifice in a manner that does not require mounts on the engine which would interfere with air flow, etc.

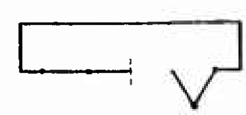
COVER REQUIREMENTS AND CHARACTERISTICS: (In order of preference)

1. Hinged doors, hoods and caps:

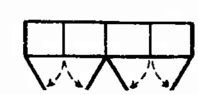
The use of hinges allows the fastest and easiest access, reduces the number of fasteners required, supports the cover so the technician does not have to handle it, and makes it unnecessary to disconnect wires or components mounted on the cover prior to entering the access. Such covers do, however, require "swinging space" and may interfere with other operations or components.

Requirements:

a. If opening space is a problem, use double-hinged or split doors, as at right.

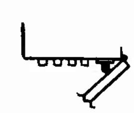


b. Place hinges on the bottom, bias the hinges or provide a prop, catch, or latch so the door will stay open without being held. This is particularly necessary if the door must be opened in high winds.
c. Adjacent hinged doors should open in opposite directions to maximize accessibility; and cabinets should be so arranged that functionally related cabinets are adjacent and open in opposite directions.



d. Hinged caps over service or test points must be so designed so as not to interfere with the insertion or attachment of service or test equipment.

e. Provide stops, retainers, etc., as necessary to prevent the door from swinging into adjacent displays, controls or fragile components, and to prevent springing of the hinges.



2. Sliding doors or caps:
   Large sliding doors may create structural design problems, but are particularly useful where "swinging space" is limited; and small sliding caps are particularly useful for small accesses that do not require a close seal.

   Requirements:
   a. Sliding doors and caps must lock positively.
   b. They must be designed to avoid jamming or sticking.
   c. They must be easy to use and should not require tools for operation.
   d. Their movement must not interfere with, damage, or provide potentially harmful contact with wires or other equipment items.

3. Removable doors, plates or caps:
   These require little space for opening and, once removed, do not interfere with work space; however, their handling requires time and effort (searching, bending, reaching, etc.).

   Requirements:
   a. Make maximum use of tongue-and-slot, or similar catches for small plates, doors and caps to minimize the number of fasteners required.
   b. Secure small plates and caps that are likely to be misplaced or damaged with retainer chains in accordance with the requirements on p. 67.
   c. If a removable plate must be attached in a certain way, design so that improper attachment is impossible--e.g., use an asymmetric plate shape, locate mounting holes asymmetrically, or label both plate and structure so the labels are aligned when the plate is properly installed.

4. Removable panels or sections:
   These are useful to permit access to whole sides of a cabinet or equipment. They discourage non-maintenance personnel from opening the access. They do not require "swinging space." But they are easily damaged, and are awkward to handle. They may also interfere with maintenance activities.

   Requirements:
   a. Panels intended to be removed for maintenance should be held with a minimum number of combination-head, captive fasteners; spring-loaded, quarter-turn fasteners are particularly recommended.
   b. Such fasteners should give position indication when they are released--i.e., release should be clear prior to movement of the panel.
   c. Panels and sections should be removable, carriable, and installable by one man with common hand-tools. (See "Tools," p. 118)
   d. Panels and sections should be provided with handles to facilitate removal, handling, and replacement. (See "Handles," p. 52)
   e. It should not be necessary to disconnect wires, components, etc., from panels before they can be removed; if such items are attached to the panel, the panel should be so hinged as to make removal unnecessary.

5. Stress doors.
   Covers and access doors on high performance equipment usually require a great many fasteners to meet operational requirements. The speed and ease with which such doors and covers can be opened and used can be greatly increased by the use of captive, quick release fasteners which satisfy the "General requirements" for fasteners on p. 62-63.

TEST AND SERVICE POINTS

DECISION FACTORS:

Requirements for testing and servicing should be avoided wherever possible by the employment of sealed bearings, oil impregnated bushings, highly reliable components, and other measures calculated to circumvent the need for maintenance.

To further reduce the number of test and service points required, provide built-in indicators, pressure guages, direct reading fluid level guages, etc., to allow quick checks without attachment or employment of auxiliary equipment.

When required, the design, location and organization of test and service points will only be effective to the degree that they are compatible and coordinated with:

a. Planned or standard test and service equipments.
b. Planned or standard checking, troubleshooting and servicing procedures.
c. Information requirements established by these procedures and equipment.
d. Work space and work clearance provisions, as discussed on p. 47-50.
e. Access requirements and provisions, as discussed on p. 42-46.
f. Cable and line requirements as discussed on p. 77-81.
g. Connector requirements, as discussed on p. 68-76.
h. The skill levels of maintenance personnel, where determinable and clearly related to design decisions.

Test and service points should be further evaluated in terms of the degree to which they:

a. Contribute to the confidence in the operability of the system.
b. Minimize the amount of effort required to obtain this confidence.
c. Simplify testing and servicing requirements and procedures.
d. Facilitate the speed and ease with which troubleshooting is accomplished.

GENERAL REQUIREMENTS:

Standardization requirements:

Test and service points should be so standardized as to:

a. Satisfy the general concepts under "Standardization," on p. 120.
b. Minimize the number of different types of:
   (1) Fuels, lubricants, voltages, etc., required.
   (2) Test and service equipment and accessories required.
   (3) Fixtures and features required (fittings, connectors, etc.)
c. Provide distinctively different connectors or fittings for each type of test or service equipment, probe, grease, oil, etc., to minimize the likelihood of error or misuse in the application of these.
d. Avoid requirements for separate funnels, strainers, adaptors, and other accessories. Where required, these should be built into the equipment or service equipment, so they need not be separately handled.

Accessibility requirements:

Test and service points should be provided, designed and located so they are accessible:

a. According to the preferences and requirements discussed on p. 42.
b. According to the priorities of frequency and time requirements of use.
c. With a minimum of disassembly or removal of other equipments or items.
d. On surfaces or behind accesses which may be easily reached or readily operated when the equipment is fully assembled and installed.

To accomplish this accessibility:

a. Collect and group test and service points at a central panel or location or at a series of functionally autonomous panels and locations.

b. Avoid locating a single test or service point in an isolated position; such points are most likely to be overlooked or neglected.

c. Provide lead tubes, wires, or extended fittings as necessary to bring hard-to-reach test and service points to an accessible area.

d. Package the equipment to overcome accessibility deficiencies resulting from critical lead lengths and similar constraints.

e. Provide <u>windows</u> to internal items requiring frequent visual inspection, e.g., guages, indicators, etc. (See "Covers and Cases," on p. 84)

f. Provide <u>tool guides</u> and other design features to facilitate operation of test or service points which require blind operation.

g. Provide test accesses to <u>mechanical components</u> subject to heavy wear. For example, provide brake assemblies with an access for insertion of a guage to determine clearance between the brake lining and drum.

<u>Location requirements</u>:

Locate test and service points so they are:

a. Recessed, guarded or otherwise protected from damage by personnel, moving cargo or equipments, dust, moisture, etc.

b. Within easy functional reaching and/or seeing distance of related or corresponding controls, displays, fittings, switches, etc.

c. Convenient to related ground support equipments and compatible, in terms of work space and clearance requirements, with the various features and characteristics of such equipments.

d. Away from dangerous electrical, mechanical or other hazards. Leave more than a hand's width (4.5") separation from the nearest hazard, and provide guards and shields as necessary to prevent injury.

e. Not concealed or obstructed by bulkheads, brackets, other units, etc., and so it is not necessary to disassemble, remove, or support other units, wires, etc., to test, service or troubleshoot.

Indicate locations of <u>internally located points</u> on the access plate or adjacent surface of the equipment.

Locate <u>safety valves</u> where they are readily accessible, but where pop-off action will not injure personnel or damage equipment.

Locate <u>fluid fill area</u> for combustible materials (fuel, oil, etc.) away from sources of heat, sparking, or potential voltage shorts.

Locate <u>fluid fill areas</u> so there is little chance of spillage during servicing, especially on personnel or easily damaged equipment.

<u>Connector requirements</u>:

Connectors or fasteners for test or service points should:

a. Be in accordance with the provisions discussed under "Connectors," p. 68.

b. Use direct insertion or quick disconnects except on pressurized systems.

c. Key the connectors on pressurized systems so they are properly seated before an opening occurs, to prevent loss of gases or fluids and reduce the hazards involved.

d. Require only hand operation. Common hand tools may be required if necessary, but special tools should not be required for the connection of test and service equipment.

e. Incorporate holding devices, clamps, and auxiliary shelves as necessary to support test probes, test sets, etc., and free the technician's hands for other tasks, such as making adjustments.
f. Incorporate guards and shields as necessary to protect personnel and test or service equipments, particularly if the equipment must be serviced while running.
g. Employ self-sealing elastomers or similar devices to allow probing into hermetically sealed units; such devices should be provided with tool guides to ensure that proper contact is made.

Labeling and coding requirements:

Labeling. Each test or service point should be provided with a label or instruction plate which:

a. Is in accordance with the discussion under "Coding and Labeling," p. 71.
b. Contains the following information, in order of priority:
    (1) A symbol or number which clearly and uniquely defines the point.
    (2) The "in-tolerance" signal symbol and/or tolerance limits.
    (3) The designation of the unit most closely related to the point.
    (4) Necessary cautions and warnings regarding use of the point.
    (5) The function or characteristic of what is being tested or the type of fuel, coolant, grease, oil, etc., to be used.

If only a symbol or number is used, this should be explained by tables placed near the equipment and/or in the job instructions and checklist.

Avoid use of the terms, "or equivalent" and "interchangeable," when listing types of fuels, oils, grease, etc. List instead specific known alternatives most likely to be available.

Coding. Test and service points should be coded with outstanding colors so:

a. They can be easily located on a piece of equipment.
b. They will be distinguishable from other fittings, breathing holes, etc., which are not to be probed or serviced.
c. The code is consistent on a given equipment unit, but stands out against the background color of the unit.
d. The code is consistent, where possible, throughout the system and does not conflict with other color code schemes used in the system.
e. The code distinguishes the following:
    (1) Primary test points from secondary test points.
    (2) Test points in general from service points in general.
    (3) Fluid filler caps. (See below)
    (4) Grease fittings.
    (5) Other items as necessary to prevent confusion or misuse.

Cap and Cover requirements:

Caps and covers for test and service points should be:

a. Provided as necessary in accordance with the preferences and requirements discussed under "Covers and Cases," on p. 82-86.
b. Spark resistant, when used for or near combustible materials.
c. Color coded according to cap function as follows: (See Ref. 48)

Cap function	Color	FED-STD-595 Color No. (Ref. 9)
Fuel filler caps	Insignia red	11136
Oil filler caps	Orange yellow	13538
Coolant filler caps	White	17875

(Other distinguishing colors as appropriate)

SERVICE POINT REQUIREMENTS:

Provision: Service points should be provided as necessary to ensure that adequate adjustment, lubrication, filling, changing, charging, and other services are provided to all points requiring such servicing between overhauls.

Fuse requirements:
Fuses should be provided so that each unit of a system is separately fused and adequately protected from harmful power line variations or transient voltages.

Fuses should be selected and located so that they are:
a. Standardized to the most practical degree. (See "Standardization" p.120)
b. Mounted on the front panel of the unit, not inside the equipment.
c. Grouped in a minimum number of central, readily accessible locations.
d. Replaceable by the equipment operator whenever practicable.
e. Replaceable without use of tools and without moving other parts.

Spare fuses should be provided and located near the fuse holder.
Labels adjacent to the fuse holder should provide both fuse value and function. If space is limited, provide fuse value rather than fuse function.
Fuse holder cups or caps should be quick-disconnect rather than screw-in in type, and should be knurled and large enough to be easily removed by hand.

Battery requirements:
Batteries should be selected, designed, installed and mounted so that:
a. Adequate accessibility is provided for replenishing the electrolyte.
b. Adequate accessibility is provided for battery removal or replacement.
c. Battery replacement requires only one man with common hand tools.
d. Dust caps are provided so battery terminals cannot contact metal surfaces during handling or removal or replacement.

Only electrical fixtures approved for hazardous locations should be used in battery compartments, to prevent gas explosions.
Quick disconnects should be provided on battery leads, for power-off maintenance or emergencies.

Labeling should be provided as necessary to identify:
a. The battery as to type, voltage, polarity, and safe rate of charge.
b. The compartment, as "BATTERY COMPARTMENT" or "BATTERY."
c. All related terminals, connectors, contacts and leads that are part of the battery circuit. (When practical, provide a block or pictorial wiring diagram of the battery circuit in addition to labels.
d. Related hazards, and particularly to ensure that:
   (1) The battery will not be charged in a poorly ventilated compartment, where explosive mixtures of hydrogen and air may result.
   (2) Batteries are removed when the unit is to be out of service for an extended period of time.

Adjustment points:
The design of the adjustment points should:
a. Satisfy the "General Requirements" on p. 87-89.
b. Satisfy appropriate tool clearance and work space requirements.
c. Require operation by hand, preferably, or common hand tools.
d. Offer positive indication, through calibration, labeling or other features, of the direction, degree and affect of the adjustment.

Adjustment controls. All adjustment controls should be designed and positioned so that:

a. They are located on a single panel or face of the equipment, or on a minimum number of functionally independent panels.
b. They are capable of being quickly returned to the original settings, to minimize realignment time if they are inadvertently moved.
c. Those that require sequential adjustment are located in the proper sequence and marked as necessary to designate the order of adjustment. (See "Coding and Labeling," p. 58 and 71)
d. Adjustments are independent of each other whenever possible.
e. Adjustment procedures are clear and straightforward, and do not require conversion or transformation of related test values.
f. Knobs are used in preference to screwdriver adjustments; the latter are generally unsatisfactory from the standpoint of easy manipulation and the requirement for tools.
g. Adjustability is avoided whenever the part values will not change during the life of the equipment.
h. The following types of adjustments are avoided except where their use will considerably simplify the design or use of the equipment:
    (1) Extremely sensitive adjustments.
    (2) "Nontamper" factory adjustments.
    (3) "System adjustments"--i.e., a component or system should be designed so that components can be replaced without harmonizing or recalibrating the whole system.
    (4) Harmonizing or "mop-up" adjustments--e.g., those that require "A" or "B" to be readjusted after A, B, and C have been adjusted in sequence.

Adjustment for wear.

a. Shim-type adjustments should be designed so that shims are removed rather than added to make adjustments, where practicable.
b. All parts subject to wear should be designed, where feasible, so they can be adjusted or repositioned to allow even distribution of the wear or to compensate for the effects of wear on part performance. For instance, the following types of parts should be easily adjustable:
    (1) Clutch and brake assemblies.
    (2) Belt-drive assemblies.
    (3) Engine carburetor linkages.
    (4) Valve-lash linkages.

Lubrication points.

a. Reduce lubrication requirements to two types, if possible, one for engine lubrication and one for gear lubrication.
b. Use the same fuels and lubricants in auxiliary or mounted equipment as in the prime unit, where practical.
c. Use easily distinguished or different types of fittings on points or systems requiring different or incompatible lubricants.
d. Provide pressure fittings for the application of grease to bearings that are shielded from oil.
e. Provide ample reservoir space for grease to bearings in gear drive units.
f. Provide a central lubrication or filler point, or a minimum number of points, to all areas requiring lubrication within a given system or component.

g. Provide lubrication points to avoid disassembly of equipment; but if such points are not feasible, provide easy access for direct lubrication.
h. Provide suitable cautions and overflow mechanisms where over-lubrication can occur and/or could cause damage to the equipment.
i. Design lubrication points so that it is not necessary to stop the equipment in order to perform lubrication operations (mobile equipment is the exception).

Fluid level indicators.
a. Direct reading gauges are preferable to dipsticks or other methods of indicating fluid levels, for they allow rapid, immediate and continuous inspection, and thus remove requirements for inspection tables.
b. Such gauges or dipsticks should be calibrated in terms of functional units (quarts, pounds, gallons, etc.), rather than general terms such as dry, low, add, etc.
c. Such gauges or dipsticks should be immediately accessible and quickly and easily read--i.e., there should be good contrast between the finish of the gauge and the fluid.
d. Fluid level indicators should satisfy the requirements under "Controls and Displays," on p. 128.

Drain points or bleed fittings:
a. Provide drains on all fluid tanks and systems, fluid filled cases or pans, filter systems, float chambers, and other items which are designed or likely to contain fluid that would otherwise be difficult to remove.
b. Use drain lines and fittings which extend beyond the fuselage skin rather than those which end inside the skin.
c. Use drain fittings of a few types and sizes, and standardize these according to application throughout the system. (See "Standardization," p. 120)
d. Use valves or petcocks in preference to drain plugs; where drain plugs are used, they should require only common hand tools for operation, and design must ensure adequate tool and work clearance for operation.

e. Drain cocks or valves should be clearly labeled to indicate open and closed positions, and the direction of movement required to open.
f. Drain cocks should always close with clockwise motion and open with counter-clock-wise motion.
g. Provide instruction plates as necessary to ensure that the system is properly prepared prior to draining.

h. Design, locate, and install drain points:
   (1) Where they are readily reachable and operable by the technician.
   (2) So fluid will not drain or spill on equipment or personnel.
   (3) At the lowest point in the system when complete drainage is required or when separation of fluids is desired.
   (4) At other points in the system as required to permit selective draining or bleeding to facilitate maintenance procedures.
   (5) To permit drainage directly into a waste container without use of separate adaptors or piping.
   (6) So fuel or other combustible fluids cannot run down to or collect in the starter, exhaust, or other hazardous areas.

TEST POINT REQUIREMENTS:

Explanation:

a. Primary test points (or operational test points) are those used to isolate malfunctions to a removable subassembly.

b. Secondary test points (or maintenance test points) are those used to isolate a malfunctioning detail part within a subassembly after the subassembly has been removed from the larger or major assembly.

Provisions:

a. Primary test points should be provided for the input and output of each line replaceable or repairable assembly, circuit, item or unit; these points should be immediately accessible.

b. Secondary test points should be provided for each bench or shop replaceable or repairable assembly, circuit, item or unit; these points need not be accessible until the assembly and/or its case has been removed.

c. Ground points and contacts should be provided as necessary, particularly where painted surfaces would otherwise prevent good electrical bond. If not otherwise obvious, such points should be clearly labeled.

d. Voltage dividers and similar mechanisms should be provided where necessary to facilitate safe measurement of voltages in excess of 500 volts, and to minimize requirements for additional types of test equipment.

e. In addition, test points should be provided as necessary to:
   (1) Improve the validity of confidence and verification tests.
   (2) Improve the efficiency of test and troubleshooting procedures.
   (3) Permit checking of units in the operating condition without the use of special rigs or harnesses.

Location: Locate test points so that:

a. Primary and secondary test points are clearly distinguishable from each other; where necessary, use color coding and labeling to ensure this.

b. Test points and their associated labels and controls face the technician, for best visibility and control of the required manipulations.

c. There is only one adjustment control associated with each test point, and this control is easily and reliably operable with the test equipment fully connected, and the technician's attention on the test set.

d. Adequate clearance is provided between connectors, probes, controls, etc., for easy grasping and manipulation. Minimum clearances are:
   (1) .75" when only finger control is required.
   (2) 2.0" when the whole hand must be used.

Arrangement:

a. Combine test points, where feasible, into clusters for multipronged connectors, particularly where similar clusters occur frequently.

b. Provide templates or overlays where they would usefully expedite the use of different test procedures which utilize the same set of test points.

c. Make maximum use of color codes, guidelines, symbols and labels to facilitate the following of logical test routines among the test points.

d. Arrange test points in a test panel or other surface according to the following criteria, listed in order of priority:
   (1) The type of test equipment to be employed at each point.
   (2) The type of connector used and the clearances it requires.
   (3) The function to which each point is related.
   (4) The test routines in which each point will be used.
   (5) The order in which each will be used.
   (6) Compromises which are conducive to rapid and accurate testing.

GROUND SUPPORT EQUIPMENT REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Ground Support Equipment (GSE)," is used here to include all forms of handling, towing, fueling, lubricating, weighing, conditioning apparatus, etc., required to support the prime vehicle. It excludes tools and non-vehicular test and service equipment.

Intent: It is not the intent of this Guide to specify operating or structural characteristics of the various types of GSE, because:

a. These are primarily the responsibility of other interests and groups, particularly Ground Support Equipment and Human Engineering groups.
b. In general, prevailing practices and regulations to this area are adequate for the purposes of this Guide.
c. These practices and regulations are well documented elsewhere. See particularly ARDC Manuals 80-5 and 80-6, (Ref. 23, 24)
d. It is not the intent of this Guide in infringe upon those responsibilities or to unnecessarily duplicate information not directly related to the basic interests of the Guide.

Support responsibility. However, where special or new-design GSE is required, Maintainability Groups should cooperate with other interested groups to ensure that such equipment is selected and designed so that it is:

a. Maintainable in accordance with relevant sections of this Guide.
b. Consistent with the general and specific requirements below.
c. Compatible with maintainability features built-into related equipment.
d. Compatible with the maintenance environment in which it is to be used.
e. Maximally useful to the technicians who must use it, in terms of the exact tasks and functions they are to perform.

GSE, then, just like the prime equipment, should be designed to:

a. Satisfy the "Standardization requirements," on p. 120-121.
b. Satisfy the "Interchangeability requirements," on p. 125.
c. Provide maximum protection for components and working parts, to minimize the need for repair.
d. Require minimal servicing, adjusting or other maintenance to remain usable throughout its service life.
e. Be as flexible and to fulfill as many required maintenance functions as practicable.

f. Satisfy real needs and requirements in such a manner as to maximally contribute to the overall rapidity, ease, economy, accuracy, and safety of system maintenance, in accordance with:
   (1) The functional requirements of the vehicle it is to support.
   (2) The service conditions under which it is to be used.
   (3) The frequency with which it is to be used.
   (4) Duration of such use and expected or required service life.
   (5) The number and capability of personnel available to operate and maintain the equipment.
   (6) Other operations which will be performed concurrently with use of the equipment.

GENERAL REQUIREMENTS:

All GSE should be selected and designed so that:

a. It is as simple as possible to operate, use and maintain.
b. The overall size is minimized so that manuverability under or around the aircraft or other prime vehicle or structure is not impaired.
c. It incorporates provisions for adjustments, adaptors, and auxiliary features to:
   (1) Make the device versatile to maximally support the technician.
   (2) Accomodate a variety of operational requirements and conditions.
   (3) Limit the overall amount of equipment required.
   (4) Allow maximum compatibility with existing equipment.

d. Equipment requirements are combined where possible into a minimum number of types and varieties of equipments, for instance:
   (1) Use a single piece of equipment for both horizontal and vertical lifting, to save time, space, manpower and cost.
   (2) Design lifts and hoists which will load and unload to the right, left, or over other packages.
   (3) Design cradles, where practicable, with built-in hoisting features to facilitate mounting and positioning as well as transportation of their loads.

Transportability requirements: (Per Ref. 48)

a. Air. Unless otherwise specified, all items of GSE should be designed to be air transportable in accordance with MIL-A-8421. (Ref. 50)

b. Rail. Equipment to be shipped by rail should not exceed:
   (1) Shipping dimensions defined in the Berne International Outline.
   (2) 124" in width or 72" in height in the shipping configuration.
   (3) 80,000 lbs for transport on a standard 40-foot flatcar.

c. Road. Equipment to be shipped by road movement should not exceed:
   (1) 78,000 lbs gross weight including the supporting vehicle.
   (2) Axle loads of 18,000 lbs, of 16,000 lbs if the axles are less than 7.5 feet apart.

d. Man. Equipment to be carried or pushed by men should:
   (1) Satisfy the "Handling requirements," on p. 115.
   (2) Require no more than two men (preferably one) for such handling.

Control requirements:

All controls for GSE should be simplified so that:

a. They satisfy requirements under "Controls and display," on p. 114.
b. It is unnecessary to manipulate large numbers of complex controls.
c. Controls do not require precise coordination.
d. The number of operations required to operate and use the device are minimized to prevent errors or oversights.

e. Speeds of movements are sufficiently slow for easy and safe management of the devices by inexperienced personnel.
f. The dangers inherent in "touchy" controls, loss of control, or control, "over-run" are minimized by design.
g. Spirit levels, guide lines, indicators, and instruction plates are provided as necessary to facilitate control of the device.

Cab or enclosure requirements:

Vehicular hoists, cranes, etc., should be enclosed to the degree warranted by the climatic conditions in which they will be used. Cabs should:

a. Be designed in accordance with good Human Engineering practices.
b. Contain facilities for heating and defrosting as required.
c. Allow adequte visibility of the work area and major working parts.
d. Rotate or move, where appropriate, with the fork, crane, etc., to allow continuous surveillance of the operation.

Fixture and storage requirements:

All GSE should be provided with the following, as appropriate, to support and facilitate the related maintenance tasks:

a. Storage space for spare parts, associated tools, manuals, etc.
b. Sufficient critical spares to ensure consistent usability.
c. Clamps, hooks, holders, etc., for cables, slings, hoses, tools, etc.
d. Lights as necessary to flood-light the work area.
e. Shelves, supports, outlets extension cords, etc., to aid use of related test or service equipments, power tools, etc.

Caster and wheel requirements:

a. Casters should be used only on shop and hangar equipment.
b. Metal casters should be avoided, as they create handling problems.
c. If feasible, a minimum caster diameter of 12" should be used.
d. Casters should pass easily over a 0.75" obstruction.
e. Heavy ground equipment should be mounted on wheels for ease of movement.
f. Wheels and casters should have brakes or locks, or be retractable to prevent movement of parked equipment.
g. When swivel-mounted wheels are used, position locks and a means for manual turning of wheels under the load should be provided to permit minute positioning of the equipment.

Towbar and coupling requirements:

a. Allow sufficient mating tolerance to make mating easy.
b. Standardize towbars and couplings for all related equipment.
c. Provide positive locking action or locking pins to avoid disconnection.
d. Provide clearances, by recess or bumper, to minimize danger to fingers and toes from dropped towbars.
e. Attach pins or other accessories with wire cable or chain so they will always be immediately available.
f. Design towbars, coupling devices and other connectors to physically prevent mis-mating or cross-connection. (See "Connectors," p. 70)

Label and marking requirements:

Labels and markings should be located as appropriate on all GSE to provide:

a. Function and motion of controls. (See "Controls and Displays," p. 114)
b. Contrast for high visibility. (See "Equipment color," p. 98)
c. A product identification nameplate in accordance with MIL-P-6906. (Ref. 44)
d. Markings pertinent to mobility in accordance with MIL-M-8090. (Ref. 41)
e. Gross weight in pounds.
f. Load limits and significant conditions under which they vary.
g. Instruction plates wherever useful and warning labels as appropriate.
h. Marks to indicate travel length, rotation angle indicators, etc., where-ever these will assist the technician in his duties.
i. Crane position signal codes or other standard operating rules and guides.

JACK REQUIREMENTS:

Jacks should be provided as required, and designed so that:

a. They can be easily transported, handled, and stored.
b. Load bearing area is sufficient to prevent overload on concrete floors.
c. Handles are provided to assist in their handling and positioning.
d. Jack handles fold or are removable to prevent:
   (1) Injury to personnel from handles thrown by slippage.
   (2) Dropping of the load by accidental bumping of the handle.
e. Man-carried jacks are in accordance with "Handling requirements," on p. 115.

Large hydraulic jacks:

These should be designed so that:

a. They are in accordance with the "General Requirements," on p. 109-110.
b. The pump, reservoir and ram assembly are mounted on a card that is designed to permit rapid and easily handling, operation, local positioning and accurate centering under the jack points.
c. The wheels are retractable or folded into the base (or the ram lowered) to allow the ram to touch the ground for greater stability.
d. A corrosion resistant oil screen is provided in the pump intake which:
   (1) Is readily accessible, removable and cleanable.
   (2) Is of sufficiently fine mesh to prevent dirt and fine particles from entering the hydraulic system.

Pneumatic bag requirements:

Such bags should be designed so that:

a. The handles will withstand a steady pull of 200 lbs.
b. Coating compounds are used which do not contain ingredients known to promote skin irritation or cause fabric deterioration.
c. The following labels are stenciled in yellow paint where appropriate:
   (1) INLET and OUTLET over these openings.
   (2) "Do not use this bag in excess of ___lbs."
   (3) "CAUTION - All traces of oil or grease shall be removed with gasoline immediately on detection."
   (4) In 2.0" letters for "CAUTION," 1.0" letters for all others.

CRADLE REQUIREMENTS:

Suitable cradles should be provided as necessary to facilitate transportation or support during maintenance of major components, such as bombs, engines, etc. These cradles should be designed to:

a. Provide sufficient bearing area to support the load securely, so the load will sit in the static loaded position without strapping.
b. Allow maintenance actions to be performed easily and quickly with the load in place (fusing, final adjustment, repair, etc.).
c. Provide metal straps or other mounts to support the intended load securely during transportation. Such straps should be:
   (1) Held by quick-disconnect, easily accessible fasteners.
   (2) Encased in non-abrasive material to protect the load surface.

When the cradle is designed to carry a particular load or loads:

a. Shape the cradle to fit the load.
b. Provide guide lines on both load and cradle so perfect positioning will be obtained merely by matching the lines. Make these guide lines visible both before and after loading.
c. Provide suitable adjustments, hoist points and positioning guide lines to satisfy the above for each different load.

Where practicable and useful, attach a platform or steps to the cradle to enable the technician to directly observe the raising and positioning of the load (bomb, engine, etc.).

Where a platform is part of the cradle provide duplicate controls for ground and platform use.

If the cradle is designed as an integral part of other vehicles or equipment, place cradle controls on a distinct and separate panel within easy reach of the operator of that equipment.

EQUIPMENT COLOR REQUIREMENTS: (Adapted from Ref. 48)

Unless otherwise specified by the procuring agency, all types of maintenance equipment should be painted in the colors indicated below. Each "Color No." refers to a color defined by FED-STD-595, (Ref. 9) with one noted exception.

Consoles and panels for operational or maintenance equipment:

a. Console panels: Gray, Color No. 36492
b. Panel lettering: Black, Color No. 37038
c. Console exterior: Green, Color No. 24300
d. Console interior: Gray, Color No. 26622 (Use only where maintenance and troubleshooting are required within console. Otherwise, standard requirements for an economical internal protective finish apply).

Vans and trailers that house equipment and personnel directly associated with operating or maintaining the direct mission elements of the system:

a. Floors: Gray, Color No. 36440
b. Walls: Green, Color No. 34670
c. Ceilings: White, Color No. 37886
d. Storage cabinets and equipment racks: Green, Color No. 24300.
e. Pipes, conduit, etc.: The same color as the surface to which they are attached, unless color coding is required.

Major ground support equipment:

a. Flight line and hanger equipment: Orange-yellow, Color No. 13655
b. Shop equipment: Aircraft-gray, Color No. 16473
c. Ground support equipment interior: Aircraft-gray, Color No. 16473

General purpose vehicles and other equipment not used on flight lines, in hangars or shops:

a. Strata Blue, Color No. 516 of MIL-E-7729 (Ref. 16)
b. Olive Drab, Color No. 24087

Markings or labels applied to equipment:

a. Gloss Black, Color No. 17038 for Insignia Red equipment.
b. Orange-yellow, Color No. 13538 for Strata Blue equipment.
c. Black, Color No. 37038 for Gray equipment.
d. Luminescent where necessary for high visibility in dark areas.
e. Other high contrast colors as acceptable to the procuring agency.
f. In accordance with concepts under "Coding and Labeling," on p. 58.

Protective devices or equipment attached to the aircraft while on the ground for safety or other equipment such as fire extinguishers which are used for emergency purposes: Insignia Red, Color No. 11136

PROTECTION AND SAFETY REQUIREMENTS:

Personnel safety requirements:

All GSE should be designed to provide maximum safety to operator and/or maintenance personnel. They should be designed so that:

a. They satisfy the "Protection and safety requirements," on p. 60.
b. Sling cables are enclosed in some form of wrapping to prevent injury to personnel or damage to equipment during use.
c. Moving parts (belts, chains, gears, etc.) are located or covered so personnel cannot be injured by them. (See "Covers and Cases," p. 82-86)

d. Handles are provided on jacks, crane hooks and similar items to allow placement or operation without endangering the technician's hands, and to facilitate handling or carrying. (See "Handles," p. 52-53)

e. All sharp or protruding edges, points, rails or corners on which personnel might injure themselves are eliminated or provided with bumper guards or covers as necessary to protect personnel.

f. Crane hooks are provided with a safety lock and ball bearing swivel, to eliminate cable twist under all operating conditions, and to facilitate ease of use and handling.

Protection of equipment:

All GSE or handling equipment should be designed to provide maximum protection of components and working mechanisms and to minimize maintenance requirements for such equipments. Design should ensure that:

a. Hydraulic or pneumatic systems are provided with gaskets or safety plugs which will "blow out" under excess pressure.
b. Stops or limit switches are provided as necessary on all moving parts and controls to prevent overtravel which would damage equipment.

c. Mechanical devices are provided as necessary to prevent inadvertent dropping of loads in the event of system failure. Check valves, ratchets, dogs, and the like are suitable for this purpose.

d. Retaining or locking devices are provided as necessary to prevent undesirable movements of turntable booms, jack extensions, etc., when the equipment is moved or transported.

e. Safety interlocks are provided on powered equipment to cut power or stop motion when the designed maximum load is reached. This will help prevent tipping or damage of the equipment.

f. Gear systems, linkages, etc., are provided with automatic devices or features to stop lifting or other action, the moment a bind or overload occurs.

g. All materials used in construction, covering, accessories, etc., for the equipment are selected to withstand the expected climatic conditions and extremes. (See "Environment," p. 126-133)

h. Covers and shelters are provided, as necessary, to further protect parked or stored equipment from moisture, dust, etc.

PLATFORMS, STANDS AND SHELTERS

DECISION FACTORS:

Platforms, stands and shelters should be provided as necessary to enable or facilitate the required maintenance within:

a. User specifications and requirements.
b. System maintenance philosophies and concepts.
c. The work space considerations discussed on p. 47-50.
d. The environmental considerations discussed on p. 126-133.
e. The "General requirements," under "Ground Support Equipments," on p. 95.

Platforms, stands and shelters should be designed and evaluated in terms of the degree to which they contribute to or detract from the rapidity and ease with which required maintenance functions can be performed. Such contributions are largely a function of:

a. The time and effort involved to obtain, transport, erect or install them.
b. The time and effort required to move, position, and/or adjust them.
c. The ease and safety of use, and general utility under expectable extreme environmental conditions, such as ran, snow, and high wind.
d. Their requirements for servicing, re-surfacing, etc. They should be so designed and fabricated as to avoid ANY requirements for maintenance to keep them serviceable.

GENERAL REQUIREMENTS:

Related requirements:

Platforms, stands and shelters should be provided with the following, where appropriate:

a. Work space and clearances consistent with the task. (See p. 47-50)
b. Non-skid surfacing where personnel must walk or stand. (See p. 47)
c. Guard and handrails as required on p. 103.
d. Stairs or ladders as required on p. 104-108.
e. Handles, eye-bolts, or hoist points as necessary to facilitate handling. (See "Handles," on p. 52-67)
f. Fasteners for removable or adjustable parts in accordance with the preferences and requirements discussed under "Fasteners," on p. 62-67.

Mobility requirements:

Platforms, stands and shelters should be permanently installed or built-in wherever possible; but where they must be used at a number of locations, they should be:

a. Light-weight and capable of being handled, erected or installed by no more than two men.
b. Collapsible or adjustable as necessary to facilitate handling, transporting or moving.
c. Provided with fool-proof, self-locking devices for all attachments, adjustments and collapsible supports.
d. Provided with wheels as necessary to facilitate moving. Wheels should:
   (1) Have wheel-locks or brakes to ensure stability during use.
   (2) Be large enough to allow easy passage over ridges up to .75" high or higher, as the operational terrain dictates.
   (3) Provide firm grip and adequate support on slippery surfaces, snow, ice, or sand.
   (4) Satisfy "Caster and Wheel requirements," as given on p. 96.

Stability requirements:

Platforms, stands and shelters should be:

a. Provided with low centers of gravity, wide wheel bases, anchors, and/or outriggers as necessary to attain the required stability.

b. Properly balanced and supported to permit use without danger of tipping when the weight of personnel and/or components is applied to any one side:

(1) On surfaces inclined up to 15°.

(2) Under expectable winds. (See "Environment," on p. 127)

(3) Under centrifugal forces encountered in towing, etc.

Fixture requirements:

Where practical and feasible, provide platforms, stands and shelters with built-in features such as:

a. Electrical outlets and fixtures to provide adequate lighting and facilitate use of test equipment and powered tools.

b. Shelves or other places for resting test equipment, tools, or components at a convenient operating or working level.

c. Hooks, eyes, clip fasteners, supports, etc. to facilitate the support and connection of associated wiring, hoses, block-and-tackle arrangements, etc.

d. Storage space, cable winders, supports, clamps, etc. to provide storage for associated manuals, slings, special tools, extension cables, etc. (See "Storage and Handling," on p. 78 and 96)

Labeling requirements:

Platforms and stands should be provided with high visibility labels which:

a. Indicate the maximum capacity in pounds.

b. Provide necessary warnings and cautions involved in their use.

c. Mark the center of gravity, where applicable.

d. Are in accordance with requirements under "Labeling," on p. 113.

Size and configuration requirements:

Platforms, stands and shelters should be of such size, shape and configuration to permit the following despite installation displacement of up to 6 inches:

a. Performance of all maintenance operations they are intended to support.

b. Reasonable combinations and variations of these operations.

c. Easy passage of personnel when access doors, cowl flaps, etc. are open.

d. Adequate work space and work clearances for the maximum number of personnel required in these operations. (See "Work Space," p. 47-50)

e. Easy access to all equipment, mounts, and features integrally related to the maintenance operations they support--e.g., to an engine, and all its associated parts, accessories, and points of connection.

f. Safe and easy handling in these operations of all related:

(1) Components that are likely to be removed.

(2) Spare parts, tools, etc., that must be handled.

(3) Slings, hoses, lines, and other supports to be handled.

(4) Cowls, panels, fairings, or other major items that must be handled within the shelter or from the platform or stand.

Platforms, stands and shelters should be standardized or made adjustable to:

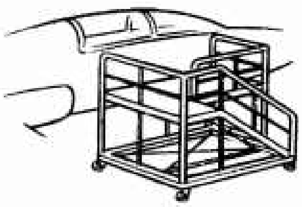
a. Minimize requirements for different types of platforms, etc.

b. Avoid or minimize requirements for repositioning the unit during use.

PLATFORM REQUIREMENTS:

Provision:

Platforms should be provided as necessary to bring maintenance personnel within optimal or at least tolerable working distance of equipment and features requiring or related to maintenance.



Requirements:

Platforms should be designed to:

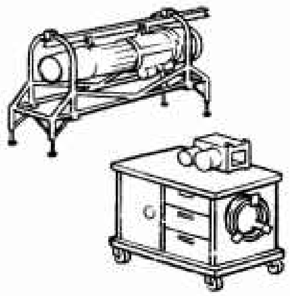
a. Satisfy the preceding "General requirements."
b. Provide a minimum of 6 square feet of work space.
c. Permit the technician to have both hands free for work.
d. Provide a continuing work surface around or between related portions of the work area--e.g., the engine.
e. Allow accomplishment of required adjustments by no more than two men in minimal time, but in no more than one-half hour.
f. Have a capacity in excess of the heaviest combination of men and/or equipments to be supported at any one time. Use 215 lbs. per man to calculate weight. A minimal capacity of one ton is recommended.
g. Conform closely to the aircraft, missile or other work surface:
   (1) General conformation should be within 2 inches.
   (2) Gaps greater than 6 inches are normally objectionable.
   (3) Contact plates, cushions, bumpers, or pads should be provided as necessary to protect equipment surfaces.

STAND REQUIREMENTS:

Provision:

Stands and rests should be provided as necessary to:

a. Provide work surfaces at the work area.
b. Elevate personnel to within optimal working distance of the work area.
c. Provide support for major units during repair, handling or transport.
d. Facilitate transport of tools and equipment to the work area.
e. Allow logical combinations of the above.



Design requirements:

Stands and rests should be designed, with consideration given to the equipment and functions they are to support, so they:

a. Satisfy the preceding "General requirements."
b. Provide adequate support and protection to equipment.
c. Maximally facilitate the associated maintenance operations.
d. Can be pushed by two men and towed by available towing equipment.
e. Are slightly larger than the equipment they support, to prevent damage to that equipment from forklifts, handling vehicles, etc.
f. Are of a height equal to that of the racks from which equipment must be removed, to minimize lifting or lowering of heavy components.
g. Are compatible in height with the slide-out tracks or rails, and/or other handling features of the basic equipment.

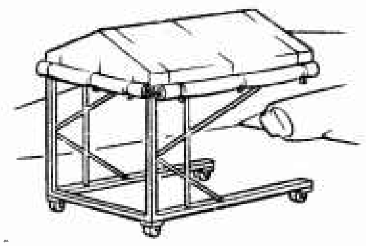
Fixture requirements:

Stands or rests should be provided with the following, as necessary, to protect, support or facilitate the handling or supported equipment:

a. Springs or shocks to prevent damage to fragile components.
b. Tie-downs or lashings to secure components during transport.
c. Built-in jacks, hoists, or adjustments to facilitate handling.
d. Mounts and special supports to protect fragile components and to ensure that equipment will not be positioned in a manner which will be harmful to it.

SHELTER REQUIREMENTS:

Shelters should be provided as necessary to enclose and protect maintenance personnel and equipment during major maintenance tasks, such as engine removal.



Shelters should be of the type and material specified by the user and in quantities commensurate with the frequency and volume of maintenance which will require their use.

Requirements.

Shelters should be designed so that:

a. They satisfy the preceding "General requirements."
b. Time to install and enclose is minimal and does not exceed one hour.
c. Maximum practical enclosure and protection are provided in terms of the environment in which the shelter is to be used.
d. Ventilation and environmental control are within tolerable limits, considering the type of clothing to be worn. (See "Environment," p. 131)
e. Allowances are made for variations in configurations of the sheltered equipment.
f. They can be used side by side where appropriate, as engine shelters are used for multi-engine aircraft.
g. Covered openings are provided as necessary to facilitate removal of major components such as propellors, fairings, or complete engines.
h. They are compatible with, provide openings for, and allow employment of associated support equipments such as cranes, stands, slings, etc.
i. Their design does not prevent operations essential to related maintenance--e.g., 360° manual rotation of propellors within the structure, regardless of landing gear shock strut position.

GUARDRAIL AND HANDRAIL REQUIREMENTS:

Guardrails and handrails should be provided as necessary to:

a. Prevent personnel from falling from elevated work places.
b. Prevent personnel from falling through floor openings, manholes, etc.
c. Keep personnel within bounds while passing through hazardous areas.
d. Assist personnel in climbing inclines, stairs, etc. (See p. 104-108)
e. Assist personnel in traversing or working in moving vehicles or in areas subject to high winds, fog, ice, or other hazards.

The construction of guardrails and handrails should:

a. Satisfy the General Requirements" on p. 105.
b. Satisfy the considerations discussed under "Handles," on p. 52-53.
c. Be between .75" and 3.0" in diameter; 1.4" is best in most cases.
d. Be supplemented with screening or latice work as necessary to insure safety.

STAIRS, LADDERS AND RAMPS

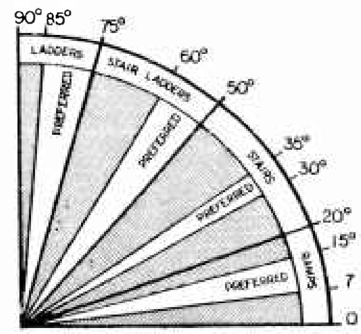
DECISION FACTORS:

Stairs, ladders or ramps should be provided at all locations where equipment design or maintenance actions require personnel to abruptly change elevation by more than 12 inches.

Stairs (stiles) and ramps may also be used to provide safe and easy passage over low objects (pipes, lines, ridges, etc.) in corridors and passageways.

The layout and design of stairs, ladders and ramps should consider:

a. Limitations in the amount of space and clearance available.
b. Expectable environmental conditions, particularly whether the structure is likely to become wet or covered with ice or snow.
c. The type, direction and frequency of traffic over the structure.
d. The relative efficiency of alternative traffic plans and patterns.
e. Loads or other encumberments to be carried by personnel in passage.
f. The size and weight of other equipments that may have to be moved over the route.



The critical difference and the primary basis of decision among stairs, ladders, and ramps is, of course, the angle of inclination of the structure as a function of the available space and structural constraints. The diagram at the right shows the preferred and critical angles of incline suitable for these structures.

TYPES OF STRUCTURES (In order of preference):

1. Stairs. Stairs allow the fastest, safest, and easiest passage of personnel, particularly personnel carrying loads (such as tools, parts, and test equipment).

2. Stair-ladders. Stair ladders are preferred to ladders; they provide better footing and faster, safer passage. But both hands are required on the handrails for sure balance and fast movement, and it is hazardous for personnel to carry loads up stair-ladders.

3. Ladders. Ladders are not desirable for frequent passage. They are comparatively unsafe, difficult to climb, and difficult to work from. Only loads which are strapped to personnel can be carried up ladders. Fixed ladders are preferable to semi-permanent or movable ladders; the former are more stable, less subject to clearance problems, and can be affixed with guardrails and other safety features. Portable ladders should be required and provided only for emergency functions or for use during infrequent maintenance tasks. Permanent ladders or maintenance stands are preferable.

4. Ramps. In general, ramps are of value only when rolling stock must be moved between different levels and this same space can be used for pedestrian traffic. Long ramps are undesirable except for self-propelled vehicles. Requirements for personnel to push or pull rolling stock up ramps should be carefully evaluated in terms of safety and human strength. (See p. 142)

Escalators and elevators will not be discussed in this guide. In general, prevailing practices and regulations covering these are adequate for the purposes of this guide; but specific applications should be carefully reviewed from maintainability, human factors, and efficiency viewpoints.

GENERAL REQUIREMENTS:

Stairs, ladders and ramps should be:

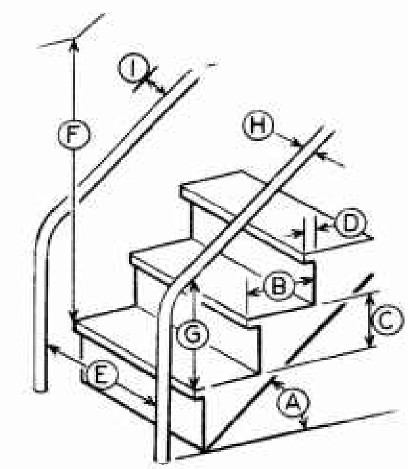
a. Designed, installed, or provided to effect the most immediate and efficient access to and between work places and areas.
b. Constructed of materials which are light-weight, non-conductive, splinter-proof, waterproof, humidity resistant, and resistant to chemical action.
c. Made strong enough to withstand the combined weights and strengths of the largest number of personnel likely to be on them at any one time, times a safety factor of at least two. Use 215 pounds per man to calculate weight. (See "Human Strength," p. 142-143)
d. Provided with nonskid surfaces on all areas where personnel are expected to step, walk or stand.
e. Cleared of obstructions, edges, notches, or burrs which could injure personnel or damage hoses and cables.
f. Designed so they may be de-iced when necessary by use of hot water or steam.
g. Adequately lighted. (See "Illumination," p. 130)
h. Adequately marked against dangers involved in their use; for instance, against unavoidable low overhead, possible shock, etc. (See "Coding and Labeling," p. 58)

Portable ladders and movable stairs and ramps should be designed to be carried, handled, and positioned by one or not more than two men.

The distance between steps or stairs (riser height) should be uniform, and the distance between steps and landings should not be less than 6 inches nor more than the uniform riser height.

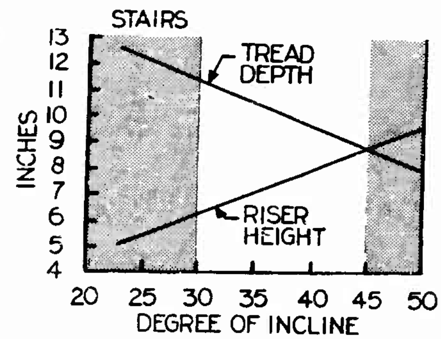
STAIR REQUIREMENTS:

Dimensions:	Min	Max	Best
A. Angle of rise:	20°	50°	30-35°
B. Tread depth:	9.5"	12"	11-12"
C. Riser height:	5"	8"	6.5-7"
D. Depth of nosing:	.75"	1.5"	1"
E. Width (handrail to handrail)			
One-way stairs:	20"	--	22"
Two-way stairs:	48"	--	51"
F. Min. overhead clearance:	76"	--	78"
G. Height of handrail	30"	36"	33"
H. Diameter of handrail:	1.25"	3.0"	1.4"
I. Hand clearance:	1.75"	--	2.0"



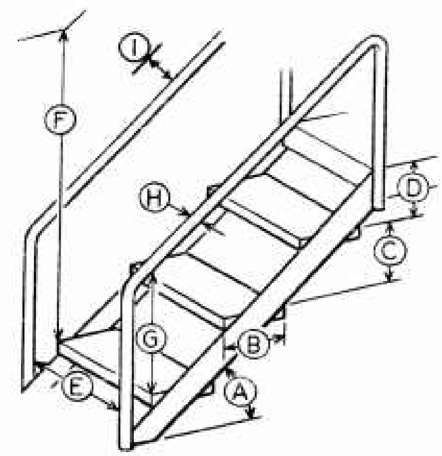
Tread depth and riser height may vary with the angle of inclination according to the graph at right. But loads carried and length of the stairs should also be considered; in general, deep treads (12") and low risers (5") should be used when loads over 20 pounds are to be carried or stairs are over two stories high.

Avoid long flights of stairs. Landings are recommended every 10-12 treads and must be provided for every story (8-12 ft. elevation).



STAIR LADDER REQUIREMENTS:

Dimensions:	Min	Max	Best
A. Angle of rise:	50°	75°	50-60°
B. Tread depth:			
For 50° rise:	6"	10"	8.5"
For 75° rise:	3"	5.5"	4"
C. Riser height:	7"	12"	8-9"
D. Height, step to landing:	6"	Riser	Riser
E. Width (handrail-handrail):	21"	24"	22"
F. Min. overhead clearance:	68"	--	76"
G. Height of handrail	34"	37"	35"
H. Diameter of handrail:	1.25"	2"	1.4"
I. Min. hand clearance	2"	--	3"

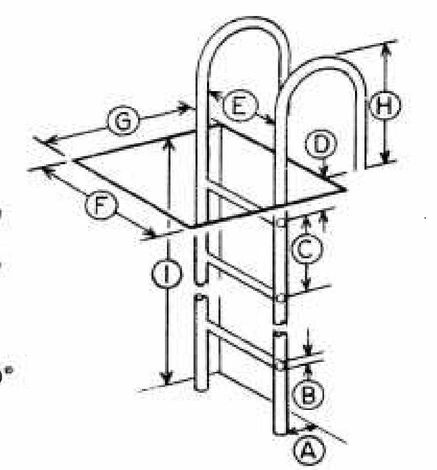


Clearance on stair-ladders should be sufficient for one person only. If simultaneous two-way traffic is desired, separate UP and DOWN ladders should be provided. If these are located side by side, a double center handrail should be provided with a min. of 6" between rails (8" recommended).

Treads should be open (without risers). But metal screening (or kick plates) should be fastened to the underside where required to prevent injury to personnel or damage to equipment.

FIXED LADDER REQUIREMENTS:

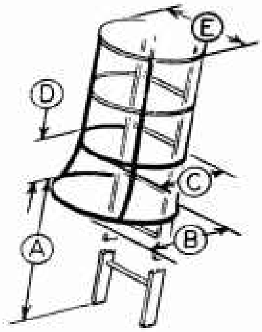
Dimensions:	Min	Max	Best
A. Angle of rise:	75°	90°	80°
B. Rung or cleat diameter:			
Wood:	1.13"	1.5"	1.4"
Protected metal:	.75"	1.5"	1.4"
Metal that may rust:	1.0"	1.5"	1.4"
C. Rung spacing (R-S):	9"	16"	11-12"
D. Height, rung to landing:	6"	R-S	R-S
E. Width between stringers:	12"	--	18-21"
F. Climbing clearance width:	24"	--	30"
G. Min. clearance depth:			
In back of ladder:	6"	--	8"
On climbing side: 36" for 76°, 30" for 90°			
H. Height of string above landing:			36"
I. Max. height of climb:	--	10ft	8ft



If ladders are used between several floors, they should be offset and provided guarded landings at every floor.

Guardrails should be provided at the top entrance to ladders, if the ladder well is open. (See "Guardrails," p. 103)

Provide ladder cages for fixed ladders over 20 feet long. Dimensions of cage should be as follows:

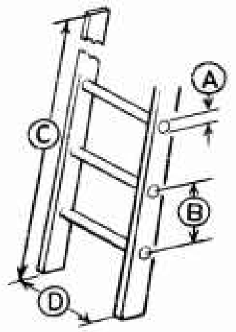


A.	Height of cage from base of ladder:	7 ft.
B.	Flare at bottom of the cage:	32"
C.	Depth of cage from center of ladder:	28"
D.	Max. distance between cage ribs:	18"
E.	Width of cage:	27"

The inside of the cage must be clear of obstructions.

Round rungs provide better hand holds, but level steps, 3-4" wide, may be used if handrails are provided on both sides of the ladder.

PORTABLE LADDER REQUIREMENTS:

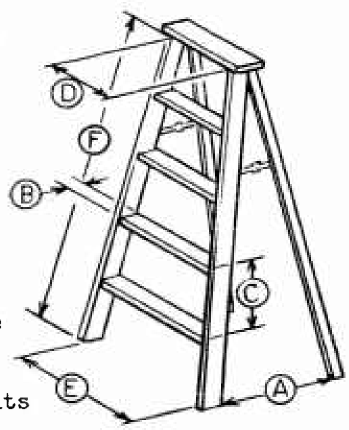


Rung-ladder dimensions:

A. Rung diameter: Same as "Fixed ladders."
B. Rung spacing: Same as "Fixed ladders."
C. Maximum ladder length:
- Single section ladders: 30 ft.
- Two-section, metal ladders: 48 ft.
- Two-section, wood ladders: 60 ft.

D. Min. width between siderails:
- Metal ladders: 12.0"
- Wood ladders:
  - Up to 10 feet long: 11.5"
  - Add .25" for each added 2 ft. of length.

Step-ladder dimensions:

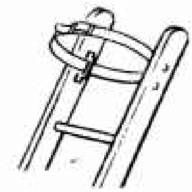


A. Spread: 3.5" per ft. length of front section plus 2.0" per ft. length of back section.
B. Tread Width: Min. 3"; best 3-4"
C. Step spacing: Min. 9"; best 11-12"
D. Min. width between siderails at top step:
- Metal ladders: 12.0"
- Wood ladders: 11.4"

E. Width at bottom: Add 1" per foot of length.
F. Length of ladder: Maximum of 20 ft.

Provide rubber cleated, pivoted feet on ladders for use in non-freezing weather, and steel cleats for use in ice or snow.

Use permanent type hinges and locks in preference to bolts and nuts for assembly of two-section extension ladders.



Provide safety devices on either fixed or portable ladders whenever length, use, or operating conditions require. For instance, provide pole lashing devices for ladders to be used against poles, or carrier rails and safety belts for long ladders to be used in adverse weather or under emergency conditions.

SPECIAL APPLICATIONS:

Design airplane exit ladders so they fit securely into receptacles located on the bulkhead. These should interlock snugly to prevent warping.

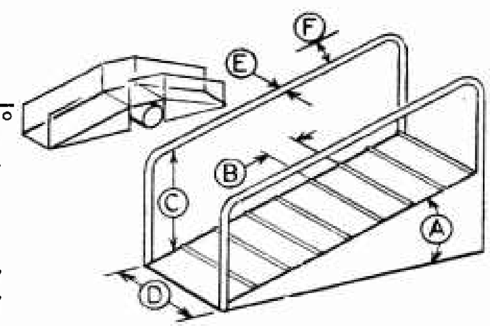
Avoid the use of mounting ladders which rest and bear on the surface of the aircraft. If these are necessary, they should be designed with large rest plates to spread the load and prevent damage to the surface of the aircraft.

Install kick plates behind ladders for special applications where feet may damage the surface of the airplane or other equipment.

Metal ladders should be marked with signs or decals warning against the danger of shock. Place these inside the stringers, on both sides, and 3 ft. from both ends: "CAUTION. Do not use near electrical equipment."

RAMP REQUIREMENTS:

Dimensions:	Min	Max	Best
A. Angle of rise:	--	20°	7-15°
B. Distance between cleats:	9"	16"	14"
C. Height of handrails:	38"	44"	42"
D. Width: Determined by function and usage. Particularly size of rolling stock and loads.			
E. Diameter of handrail:	1"	3"	1.4"
F. Clearance around handrail:	2"	--	3"



Where a smooth surface or runway for wheeled vehicles is needed, it should be located in the center or to one side of the ramp, with cleated portions on the outside below the handrails. A combination of ramp and stairway is preferred, however, especially for slopes greater than 7°.

TEST EQUIPMENT REQUIREMENTS

DECISION FACTORS:

The determination of the needs for and types, quantities, qualities and general characteristics of test equipments can only logically follow from a systematic and thorough analysis of system test requirements, significant maintenance environment factors, and the relationships between test and prime equipment. The steps involved in such an analysis are outlined below.

1. Data Collection.

System test requirements should be exhaustively and thoroughly determined in accordance with established data collection requirements. The data so collected should contain the following information for each new or modified unit, subunit, or assembly, down to the replaceable module or part:

a. All operations required to test, check or troubleshoot the unit.
b. The important parameters involved in each operation.
c. Critical tolerances and/or decision criteria (standards) for each parameter on each operation, particularly those which define:
   (1) Optimal performance.
   (2) Acceptable performance.
   (3) Notable or determinable malfunction symptoms.

d. Methods by which each operation, tolerance or criterion is obtainable.
e. Instrumentation requirements implied by each method.
f. Inter-relationships among the operations--e.g., the sequence with which they must be performed, parametric dependencies, etc.
g. Limitations or constraints placed on each operation or method, as:
   (1) "Noise" problems and consequent filtering requirements.
   (2) Notable hazards or dangers to either equipment or personnel.
   (3) Work space, critical lead length, inductance, etc.

h. Time required to perform each operation.
i. Criticality of each operation to system readiness or performance.
j. Frequency with which each operation must be performed, based upon:
   (1) Reliability data.
   (2) Maintenance philosophies or preventive maintenance routines.
   (3) The required operating efficiency of the tested equipment.

2. Environmental Data.

Related data should be gathered simultaneously regarding the maintenance environment in which testing is to be done, particularly with regard to:

a. The environmental extremes to be withstood by the device.
b. Maintenance procedures and policies of the potential system users.
c. Symbols, codes, etc. commonly employed by or familiar to the user.
d. Methods of information presentation, data collection, or maintenance feedback employed by or familiar to the user.

e. Purposes for which the tester will be employed, in terms of what the technician must do with the information obtained from the tester.
f. Tasks involved in use of the tester from maintenance task assignment to return of the tester to storage.
g. Manner of transport of tester from storage to place of application:
   (1) How far must it be transported? By what means?
   (2) What vibration and shock conditions will it be subject to?
   (3) Will it be moved from one environmental extreme to another?

3. Functions analysis.

The data thus collected should be integrated and organized into functional categories by established functions analysis procedures to determine:

a. Which operations are performed at the same maintenance level.
b. Which operations are performed by the same maintenance specialties.
c. Which operations are performed in the same maintenance assignment.
d. Which operations are commonly associated together.
e. Which combinations of parameters are frequently measured together.
f. What sequences or other relationships exist among these operations in terms of those levels, specialties, and assignments.

g. What other communalities exist among the operations, parameters, or assignments in terms of power requirements, tolerances, etc.
h. Which test requirements can be best satisfied, in terms of the goals given below, by the following (in order of preference):
   (1) Standard or off-the-shelf-test sets.
   (2) A new general tester--one applicable to many systems.
   (3) A new common tester--one applicable to many system units.
   (4) A new special tester--one unique to the system or unit.

4. Performance specification.

The general characteristics of each new or proposed device should then be specified in such a manner as to best satisfy the following goals:

a. Test or tester requirements should be minimized wherever possible.
b. A means should be provided to accomplish every required measurement.
c. Each device should satisfy as many related requirements as practicable.
d. Requirements for specialized testers should be kept to a minimum.
e. The number of test devices required for a given maintenance assignment should be as few as possible, preferably none or one.
f. The need for and unique role of each tester should be clearly justified in terms of the number, frequency, importance, and independence of the required maintenance operations.

g. Each tester should incorporate the most efficient sequence of tests to:
   (1) Simplify each testing, checking or troubleshooting routine.
   (2) Provide maximum utility and usability to the technician.
   (3) Allow checkout with the fewest possible checking operations.
   (4) Localize malfunctions in the fewest and quickest possible steps.
h. Device characteristics should be clearly specified in terms of requirements for:
   (1) Classes or types of information to be obtained and presented.
   (2) Test points or other connections to the tested equipment.
   (3) Switching from one function or purpose to another.
   (4) Different display channels for differing items of information.
   (5) The required accuracy to encompass the various tolerances.
   (6) The sequence and precision with which manipulations must be made.
   (7) The required operating efficiency and reliability of the tester.
   (8) The calibration requirements to obtain this efficiency.
i. A simple method of checking the accuracy of the tester should be provided which:
   (1) Furnishes a positive and decisive measure of the tester's accuracy.
   (2) Minimizes the number and complexity of calibration equipments.
   (3) Allows standard testing apparatus to be used at all echelons.
   (4) Allows the tester to be easily checked to determine whether it is calibrated or otherwise functioning properly.

5. Development.

The final configuration of each test device, of course, must include a thorough consideration of the following factors. Where conflicts exist, they should be resolved by agreement among representatives of the related interests:

a. The "General requirements," outlined below.
b. Reliability of the device.
c. Producibility and manufacturability.
d. Permissible cost as measured against utility and value of the device.
e. Maintenance or test requirements of the tester itself.
f. Safety considerations involved in design or use of the device.
g. Relationship of the device to other equipment, manuals, etc.

In development, preliminary panel designs, full scale mockups, and other suitable methods should be utilized to check design against relevant criteria and particularly for usability and compatibility in relation to the tested equipment.

Decisions among portable, built-in, automatic, etc. devices should be made in terms of the decision factors stated in Section II of this Guide, and considerations discussed under each of these topics below.

GENERAL DESIGN REQUIREMENTS:

Usability requirements:

Irrespective of the engineering sophistication of the device, unless the technician recognizes it as being useful, reliable, and operable, he will not use it, and the design effort is, for all practical purposes, wasted.

The following list provides common complaints and/or reasons for not using available test devices. Each of these is due to inadequate consideration of the user in design, and should be avoided in the design of new devices.

a. The device is too clumsy, heavy or awkward to carry to the job.
b. There is an unnecessarily large number of different test devices.
c. Procedures and displays are inconsistent from device to device.
d. There is confusion as to the accuracy, operation, or purpose.
e. The device is inaccurate, unreliable, or too often out of tolerance.
f. Calibration is too difficult and keeps the device out of use too much.
g. The device is not compatible with the tested equipment—e.g., connectors are too loose or too hard to reach, and leads are not long enough, or work space is too small for use of the device.

In order to design for usability, the designer must understand that:

a. Technicians are usually not trained to use complex devices.
b. Technicians avoid using devices they do not understand or find difficult to operate.
c. Supervisors hesitate to let technicians use expensive, complex equipment when the operation of the equipment is not easy or self-evident.
d. When test equipment is overly complex and poorly human engineered, the technician:
   (1) Must spend a lot of time and effort to learn to operate it.
   (2) Tends to make errors in usage.
   (3) Can only learn to operate a small number of devices well.
   (4) Finds that habits developed with one device interfere with his learning to use or operate another device.

e. Military testers which are drab, unattractive, and appear to be rugged, actually get rougher treatment than those which look fragile or have eye appeal. It is therefore recommended that testers be designed to look no tougher than they are, and to compensate for the rough treatment they are likely to receive.

Construction and packaging requirements:

The design, construction and operation of test equipment should be compatible and in accordance with:

a. The "Mounting and Packaging requirements," on p. 54-61.
b. The considerations discussed under "Standardization," on p. 120-121.
c. The considerations discussed under "Interchangeability," on p. 125.
d. The "Test and Service Point requirements," on p. 87-93.
e. The "Protection and Safety requirements," on p. 60 and 99.
f. The "Battery requirements," on p. 90, where approriate.

g. The "Unitization requirements," discussed on p. 122-3, and particularly:
   (1) The need for checking, testing or troubleshooting each module.
   (2) The need to provide a readily discernible change in signal output or wave form between successive modules.
   (3) The need for decisive, unambiguous determination of whether each module is within specified performance ratings.

Test devices should be reinforced, shielded and ruggedized to compensate for the stresses involved in their use, such as:

a. The shocks and vibrations involved in transportation.
b. Bumps and stresses from being dragged across equipment surfaces.
c. Pressures from their being used as seats, steps or workstands.
d. Impacts from their being dropped.

Major points and percentages of impacts on hand-carried test equipment are:

a. The rear, bottom, outside corner.	73%	(See Ref. 40)
b. The rear, bottom, surface.	19%	
c. The front, bottom, outside corner.	6%	
d. The rear, outside edge.	2%	

The equipment should be further designed and packaged so that:

a. Wear surfaces or "feet" are provided at points of maximum wear.
b. The device is fail-safe, thus preventing damage to the prime or tested equipment by tester failure.
c. Circuit breakers and fuses are provided to safeguard against damage in case the wrong switch or jack position is used. (See "Fuses," p. 90)
d. Adjustments, panel removal, or repair can be accomplished with a minimum number of common hand tools, preferably a single screwdriver.

e. Lids are permanently attached (hinged) to the device or carrying case and are supported so they will stay open when in use.
f. All panels are hinged or are completely removable to allow complete exposure of the inner components. (See "Cases and Covers," p. 82-86)
g. Shock absorbers are provided as necessary to protect fragile or sensitive devices, parts or instruments. These should be provided:
   (1) Within the carrying case, where desirable.
   (2) Directly on especially fragile or sensitive parts or displays.
   (3) As required to hold dial pointers, etc., stationary during transportation.

Connector requirements:

Connectors between the tester and tested equipment should be designed to:

a. Satisfy preferences and requirements under "Connectors," on p. 72.
b. Prevent criss-crossing or mis-mating. See "Connectors," on p. 70.
c. Require minimal time for full connection of the test device.
d. Use selector switches rather than a multiplicity of receptacles.
e. Accomodate the required variety of test leads.
f. Assure that connectors and pins are strong and easy to insert, but will not fall out; pin damage is a most frequent failure of testers.
g. Standardize connectors so they are identical for a given tester and requirements for different modes or adaptors are avoided.
h. Allow unit testers to checkout the replaceable unit through its own interconnecting plugs—i.e., without special test points, etc.

Leads for these connectors should be designed so that:

a. They are long enough for all the required applications.
b. They have sufficient slack for 6 replacements of the probes, etc.
c. Test probes have handles which are long enough to be held comfortably.
d. Contact points on probes are strong enough to prevent breakage.
e. Power leads, especially, are permanently attached to the tester.
f. Other leads, where possible, are permanently attached to tester.
g. Insulation is provided as necessary to eliminate shock hazard.

Labeling requirements:

Test equipments should be labeled and coded:

a. In accordance with requirements under "Labeling and coding," p. 89.
b. In accordance with requirements under "Packaging," on p. 58.
c. As necessary to ensure that they will be turned off when not in use.
d. So every removable part, such as adaptors, leads, etc., is identified with its official Air Force nomenclature.
e. So every item which the technician must recognize, read, or manipulate is clearly and unambiguously identified by name or function.
f. So space is provided on which the date of the last and next periodic calibration can be written, as appropriate.

The following should be provided on the exterior or carrying case of the device.

a. A product identification nameplate in accordance with MIL-P-6906. (Ref. 44)
b. The name and purpose, use or function of the device.
c. The location where the device is to be stored.
d. The correct power source, if applicable.
e. Special cautions to be considered in its selection or use.

Instructions should be provided:

a. On the face of the tester, in the lid or in a special compartment.
b. In a step-by-step fashion, numbered or lettered in serial order.
c. In easy view while the device is operated.
d. In simple language, avoiding uncommon terms or symbols.
e. As complete and detailed as required, but strictly job oriented.
f. Which are large enough to be clearly and easily read in poor light.
g. In larger type or in color codes for emphasized material.
h. In a different color and headed with a distinguishable title where more than one instruction list is required.
i. As a reminder that the device must be calibrated, especially if calibration is required before each usage or change in usage.

Control and display requirements:

Test equipment should be designed so controls and displays:

a. Satisfy considerations under "Controls and Displays," on p. 95.
b. Are as few in number and as simple to operate as possible.
c. Are all on a single panel or on simultaneously visible panels. Controls used only in calibration should be segregated.
d. Are located and numbered in the order in which they are to be used.
e. Are ruggedized to withstand the rigors of long and hard use.
f. Are standardized so those serving the same or similar functions are the same or similar--i.e., so habits learned on one device contribute to or at least do not interfere with using another device.
g. Use color codes where practicable to:
   (1) Make operation and relationship to instructions clear.
   (2) Relate the scale to its selector switch or switch position.
   (3) Differentiate scales, displays, instructions, etc.

"Set-up" or operation of the device should:

a. Require as few and as simple and quick operations as possible.
b. Never require use of more than two hands at any one time.
c. Be simplified by "ganging" controls or making some sequences automatic.
d. Make the order of operation unimportant--i.e., so performing one operation before another will not be an error or damage the device.
e. Be built-in, where order of operation is necessary, so controls will not operate unless the proper sequence is used.
f. Accomplish laborious or difficult steps through automatic circuitry or linkages within the device rather than through manual adjustment.

Readouts or indications should be in directly usable form:

a. They should give only the degree of information required.
b. They should give all of the information required.
c. The need to convert or transform display values should be avoided.
d. Where conversion is required, tables or factors should be provided beside the switch or scale requiring use of the factor.
e. If possible, only the scale being used should be visible during use.
f. If arbitrary scales are used (go/no-go, etc.), the "real" scale (voltage, etc.) should also be provided, though less conspicuously.
g. Dial windows should be break-proof, scratch-resistant, and glare-proof.

Warning or safety signals or devices should be provided as necessary so that:

a. Considerations under "Protection and Safety," on p. 99 are satisfied.
b. Auditory signals are provided when changes must be noted immediately.
c. A light is ON when the tester is ON, and OFF when the tester is OFF.
d. Power switches shut-off automatically when lids are closed.
e. When warm-up time is critical, a signal indicates this condition. If this is impractical, warm-up time should be clearly indicated near the warm-up switch.
f. The technician may assume the device is working properly unless he receives an indication to the contrary. When a switch is moved, a light should turn ON if the instrument is not performing correctly.
g. Indications are provided if the correct manipulation has not been performed before testing is actually done; for instance:
   (1) The orientation of switches for a given routine should provide a pattern such that the misplacement of one stands out.
   (2) A signal or warning light should come ON if the control position is incompatible with the routine.

Storage requirements:

Adequate storage space should be provided within the device, its lid or its handling case, for:

a. All removable items such as leads, adaptors, probes, or extensions.
b. Critical spare parts essential to ensure consistent usability.
c. Associated manuals, overlays, templates, etc.
d. Any special tools required for or related to use of the device.

The proper storage position of each item should be indicated by outlines, color coding, labeling, or instruction plates.

Clips, clamps, cable winders or holders should be provided to secure the stored items. Failure to provide such holders causes damage to dials and other parts when lids are closed on the cables.

Adaptor requirements: Adaptors should be:

a. Eliminated, wherever feasible, by standardization or by incorporation into the body of the tester or its connectors.
b. Easy to attach securely to the tester where required.
c. Provided with every tester as a piece of removable equipment.
d. So designed that it is not necessary to remove sections of the device before the adaptor can be attached.

Handling requirements:

The weight and dimensions of portable test equipment should be as provided below:

	Hand-held		One-man		Two-men		
Dimensions:	Best	Max	Best	Max	Best	Max	Remarks for two men.
Weight (lbs):	3	5	14	25	45	90	For short distance only.
Height:	2"	4"	13"	18"	13"	18"	Below handles.
Length:	8"	10"	16"	18"	--	--	Preferably less than 20".
Width:	4"	5"	7"	10"	--	--	See "Work Space," p. 50.

Further requirements:

a. Requirements for two-men handling of portable devices should be avoided.
b. Stands or casters for devices over 30 lbs. should be considered.
c. Wheels, casters or hoist-lifting should be provided for devices over 90 lbs.
d. Larger units should comply with general "Ground Support Equipment requirements," on p. 94-99.
e. Devices should be of rectangular shape, so they can be easily stored.

f. Handles should be provided which:
   (1) Are in accordance with "Handle requirements," on p. 52-53.
   (2) Allow the device to be easily handled and carried.
   (3) Are recessed, hinged or folding to reduce storage space.
   (4) Are molded to fit the hand and knurled to ensure a secure grip.

g. Hooks or other devices should be provided on the tester and/or on the prime equipment to enable physical attachment of the device to the equipment during use.

h. Storage space shelves, sliding or folding supports, or other devices should also be provided on the prime equipment where practicable to support the test equipment during its use.

PORTABLE HAND HELD DEVICE REQUIREMENTS:

Hand-held test equipments should be designed so they:

a. Satisfy relevant aspects of the "General requirements," above.
b. Serve only one, or at most, two functions.
c. Are provided when testing is frequent or location is inaccessible.
d. Are shaped to fit the technician's hand.
e. Can be held and operated at the same time with one hand.
f. Are serrated or ridged to facilitate secure gripping.
g. Are self-powered and do not require attachment to an electrical outlet.
h. Have a strap or hook for suspension around the neck or from the basic equipment when freedom of both hands is desired.

Battery powered test equipment should contain:

a. An insert specifying when the battery should be changed.
b. An insert which permits logging of battery changes.
c. A built-in tester which indicates when battery power is too low.
d. Sealed batteries or sealed battery compartments, to prevent equipment damage from corrosion.

AUTOMATIC CHECKOUT EQUIPMENT (ACE) REQUIREMENTS:

The primary function of ACE is to check the system prior to operation, rather than monitor its function. Thus, ACE may be either appended to the prime equipment or independently packaged and connected when needed (in trailers, consoles, etc.). In either case, considerable built-in circuitry is assumed.

ACE should be provided in accordance with the considerations in Section II of this Guide and the type of analysis outlined under "Decision Factors," above.

Design requirements:

The exact nature and character of ACE is so dependent upon the nature of the prime equipment and the circumstances of its use, that no attempt can be made here to provide definitive requirements. However, to be fully effective, ACE should:

a. Allow connection and "set-up" with minimum time and effort.
b. Comply with relevant sections of this Guide.
c. Comply with the "General requirements," above.
d. Control stimuli to the system undergoing test.
e. Be able to evaluate signals from the system against tolerances or standards which can be programmed.

f. Have fail-safe circuitry throughout both tester and prime equipment.
g. Self-verify every step in the test procedure.
h. Automatically sequence test operations.
i. Automatically verify the proper functioning of the tester.
j. Automatically localize malfunctions in both tester and prime equipment to the replaceable package or module level.

k. Be simple to operate and maintain.
l. Require minimum calibration and support.
m. Monitor operator displays and provide a permanent record of results.
n. Provide controls to re-check or by-pass portions of the program.
o. Impose minimum judgement and interpretation upon the operator.
p. Allow decisions on a positive, unambiguous, objective basis.
q. Provide templates or overlays for use in data reduction.

BUILT-IN TEST EQUIPMENT:

Built-in test equipment can be of two types:

a. A piece of standard equipment physically appended to the prime equipment.
b. A completely integrated portion of the prime set itself.

Provision:

Built-in test equipment should be provided when and in proportion to the degree that the following conditions exist:

a. The prime equipment must operate within extremely small tolerances.
b. Very frequent observation or measurement is required.
c. Faulty operation can cause extensive damage to other parts of the system.
d. There is a limited amount of storage or work space, but little restriction of the size and weight of the equipment.
e. The equipment contains many redundant or similar circuits or modules.
f. Special test inputs of a complex nature are required.
g. Safety of personnel is endangered by other testing procedures (such as testing of high pressure lines or toxic materials).
h. Testing would otherwise require disassembly of equipment or transmission lines.

Advantages of built-in test equipment:

a. The test equipment is always immediately available.
b. The choice of tester is always obvious.
c. It does not need to be transported.
d. It does not need to be designed to withstand the shocks of handling.
e. It does not require elaborate set-up procedures.
f. It needs only the simplest controls.
g. It is less likely to be lost or damaged.
h. It requires no special storage facilities.
i. It can be specialized for the specific prime equipment and function.
j. Personnel are not required to enter equipment for testing, thus reducing danger to fragile or sensitive components from personnel movements.

Disadvantages:

a. A complete set must be provided for each prime unit.
b. It can only be used for the functions designed into it.
c. Internal circuitry must be more complex and is thus lower in reliability.
d. It adds to the weight, size and space requirements of the prime unit.
e. A more careful design is required in the associated checkout equipment.
f. Calibration and modification present serious problems.
g. Modification (new parts, new voltage drains, etc.) of the prime equipment generates considerable problems for the built-in test routines, equipment calibration, etc.
h. The magnitude, duration and cost of development efforts are likely to be considerably higher. In this connection it has been estimated that:
    (1) Equipment development costs may increase by 25%.
    (2) Ground checkout development costs may increase by 50%.
    (3) Development time may increase 10-20%.
    (4) Increase in weight and volume of the prime equipment could probably be limited to 15%. (See Ref. 42)

TOOL REQUIREMENTS

DECISION FACTORS:

The design of tools, per se, is not a function of design for maintainability, simply because tool design is usually accomplished apart from the general system development program.

However, it is the responsibility of the Maintainability Engineer to insure that equipment design is such that the system is maintainable (in order of priority):

a. Without tools, where possible.
b. With the minimum number of tools, for the system.
c. With the minimum number of tools per maintenance assignment.
d. With common hand tools, to the degree practicable.
e. With Air Force standard tools only, so far as possible.
f. With special tools as required according to the provisions below.

Responsibility:

The Maintainability Engineer can discharge this responsibility by ensuring that:

a. Designers are cognizant of the above priorities.
b. Designers are aware of design relevant Air Force tool lists.
c. Special tool requirements are adequately justified.
d. Tool requirements are coordinated among design groups so the efforts of different groups (or subcontractors) result in common requirements.
e. Tool requirements and provisions are in accord with discussions under:
   (1) "Fastener Requirements," on p. 62-67.
   (2) "Standardization Requirements," on p. 120-121.
   (3) "Mounting and Packaging Requirements," on p. 54-61.

Justification:

The reasons for the priorities listed above and the justification for concern over tool requirements, are the effects of these requirements on system maintainability as illustrated by the following "facts of life:"

a. Technicians generally tend to:
   (1) Avoid carrying heavy tool boxes, or large numbers of tools.
   (2) Carry only commonly used tools.
   (3) Lose, misplace, and misuse rarely used tools.
   (4) Use improper tools, which may damage the equipment, rather than search for the proper one.

b. It is time consuming for the technician to:
   (1) Search through a large array of tools for a needed item.
   (2) Go to the tool room for tools too costly or rare for general issue.
   (3) "Chase down" a tool when it isn't in the tool room--e.g., find the man who has it checked out, and wait for him to finish with it.

c. Special tools tend to be:
   (1) Costly and difficult to supply.
   (2) Left in locked tool boxes or cabinets, or otherwise be unavailable.
   (3) In use at one place when they are needed at another.
   (4) Delayed in development or procurement so they are not available when the system is put into the field.

Methods:

Designers can be made aware of what tools are normally provided for particular Air Force maintenance specialties, by reference to:

a. Air Force tool lists, such as those listed in the table below.
b. Shorter lists derived especially for the given project.
c. Displays of pictures or drawings of the tools to be used to maintain the unit being designed by the group.
d. Actual tool boards or pictures of tool boards which display the tools to be used.

Contractor tool lists should never exceed Air Force lists. Where tool requirements can be reduced, the customer should be notified as to what items can be deleted without affecting maintenance of the new equipment.

Representative Air Force Tool Lists

Tool List	Maintenance Specialty
ECL 14216 (B)	Aircraft Propellor Technician and Repairman
ECL 14216 (D)	Aircraft Electrical Technician and Repairman
ECL 14216 (E)	Aircraft Hydraulic Technician and Repairman
ECL 14216 (C)	Mechanical Accessories and Equipment Technician and Repairman
ECL 14318 (A)	Aircraft Technician and Mechanic
ECL 14318 (B)	Reciprocating Engine Technician and Mechanic
ECL 14318 (C)	Jet Engine Technician and Mechanic
ECL 14401	Kit-office Machine Mechanic
ECL 14702	GSE Ground
ECL 15312 (A)	Machinist
ECL 15312 (B)	Metal Processing Technician and Specialist
ECL 15312 (C)	Airframe Technician and Repairman
ECL 15502 (C)	Kit-woodworker
ECL 15503	Kit-painter
ECL 15809 (B)	Kit-fabric, Leather and Rubber

Special tool requirements:

Requirements for special tools can be justified only where:

a. Reasons peculiar to the equipment or situation demand or cannot avoid their use.
b. Elements of the equipment must be "locked" after being repaired in carefully controlled or special conditions.
c. Elements of the equipment should only be maintained, changed or adjusted under special conditions or by a very limited group of specialists. (Such elements should be avoided where possible.)

STANDARDIZATION REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Standardization," here denotes any effort to select, design, or manufacture parts, assemblies, equipment, or associated tools, service materials or procedures, so they are identical to or physically and functionally interchangeable with other parts, etc., which are (in order of preference):

1. Presently in the user inventory.
2. Presently planned for the user inventory.
3. Rated in the Qualified Parts List.
4. Accepted as standard by user authority or general custom.
5. Proven by other usages or company policy.
6. Used in other parts of the system, subsystem, or unit.

Standardization is not for the purpose of inhibiting design improvement efforts. Before such efforts are undertaken, however, it should be established that their value outweights the advantages of standardization.

Rather than being a matter of initiative or freedom, the lack of standardization seems largely attributable to poor communication among contractors, users, buying agencies, subcontractors, and their divisions and agencies. It is suggested that the maintainability effort concern itself with this lack and assume responsibility for ensuring and coordinating compatibility and uniformity in design.

Goals of Standardization:

The standardization effort should seek to:

a. Reduce the number of different models and makes of equipment in use.
b. Maximize the use of common parts in differing equipment.
c. Minimize the number of differing types of parts, assemblies, etc.
d. Use only a few basic types and varieties of parts, assemblies, etc.
e. Ensure that these basic types are:
    (1) Readily distinguishable to prevent misapplication.
    (2) Used consistently for given applications.
    (3) Maximally compatible with existing uses and practices.

f. Control, simplify and reduce supply, storage and stock problems.
g. Control, simplify and reduce part coding and numbering practices.
h. Maximize use of standard off-the-shelf items and components.
i. Maximize use of interchangeable parts, etc. (See p. 125)
j. Minimize the number of "parts peculiar."

Advantages of standardization:

A well planned standardization program will tend to:

a. Avoid requirements for special or close tolerance parts, etc.
b. Save design time, manufacturing cost, and maintenance time and cost.
c. Result in more uniform and predictable reliability.
d. Minimize the danger of misapplication of parts, assemblies, etc.
e. Prevent accidents which arise from improper or confused procedures.
f. Facilitate "cannibalizing" maintenance procedures.
g. Reduce errors in wiring, installation, replacement, etc., due to variations in attributes and characteristics of similar equipments.

GENERAL REQUIREMENTS:

References:

a. Use standard AN, MS, or JAN parts wherever possible.
b. Use NF threads except for taps in soft materials and related fasteners.
c. Use electronic parts from MIL-STD-242 wherever possible. (Ref. 13)
d. Use electron tubes from MIL-STD-200 wherever possible. (Ref. 14)
e. Design for broad climatic extremes, in terms of MIL-STD-210. (Ref. 5)
f. Make use of user specific qualified parts lists.
g. Make use of specific inventory lists, where possible.

Administrative responsibility:

a. Parts or equipment manufactured by different contractors should be made uniform by agreement with the procuring activity.
b. Contractors should ensure that standardization requirements are met and satisfied by all subcontractors in a uniform and consistent manner.
c. Each contractor should ensure that his own equipment satisfies the goals of standardization outlined above.

Design requirements:

a. Design for liberal performance margins, rather than to be just adequate, to allow wider employment of a given part, assembly or unit.
b. Limit and standardize tool and tool requirements by designing equipment to be maintainable with common tools in current usage. (See p. 119)
c. Use the same lubricants, fuels, greases, fittings, etc., for ground support equipment as for the prime equipment, wherever possible.
d. Design parts symmetrical about a center line to avoid requirements for right and left hand parts.
e. Specify standard sizes and gauges, for example:
   (1) Bar diameters in 1/4" increments.
   (2) Large bolt and capscrew diameters in 1/4" increments.
   (3) Large bolt and capscrew lengths in 1/2" increments.
   (4) Small bolt and screw diameters in 1/16" increments.
   (5) Small bolt and screw lengths in 1/4" increments.
   (6) Other parts in similarly distinct increments.

Specific applications:

Use standardized or preferred parts, circuits, etc., particularly for:

a. Operating levels, inputs and outputs or circuits.
b. Values of regulators, supply voltages, etc.
c. Routine functions such as RF, IF, audio, video or computer circuits.
d. Arrangement and packaging schemes. (See p. 54-55)
e. Part identification methods and practices.
f. Labeling and marking practices and methods. (See p. 58)
g. Wiring identification and other coding. (See p. 71)
h. Selection, application and mounting of covers and cases. (See p. 82-86)
i. Selection and application of fasteners. (See p. 62-67)
j. Servicing materials and equipments, particularly oils and fuels.
k. Items which are interchangeable from equipment to equipment, such as starting motors, generators, air cleaners, oil and fuel cleaners, batteries, radiators, instruments, controls, lights, etc.

UNITIZATION REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Unitization," here denotes any effort to design, package and manufacture a group of parts and elements in an aggregate which can be regarded and handled as an undivided whole.

Goals of unitization:
Equipment should be unitized and/or divided into unitized subassemblies or modules to the maximum practicable degree consistent with the design requirements given below and the following goals (listed in order of priority) which are to:

1. Maximize reliability.

2. Optimally utilize and complement the diagnostic capabilities of test equipment, procedures, and technicians.

3. Facilitate efficient division of maintenance responsibilities among the various maintenance levels, and, specifically, to:
   a. Maximize the efficiency and accuracy of replacement at the line.
   b. Facilitate and minimize troubleshooting time at each level.
   c. Minimize duplication of maintenance efforts between levels.
   d. Permit production line repair at the higher maintenance levels.
   e. Permit use of automatic or semi-automatic techniques where practicable.
   f. Allow test, checkout, troubleshooting, and repair procedures to be unit specific, and structured to aid in identification of faulty units, then sub-units, etc.

4. Contribute to the development and use of a group of standardized, debugged, and proven modules that can be used as reliable building blocks in a number of diverse applications. (See "Standardization," p. 120)

DESIGN REQUIREMENTS:

Related requirements:
The design of units or modules, and related decisions, should be consistent and in accordance with:
   a. Accessibility preferences and criteria as discussed on p. 42-46.
   b. Connector preferences and criteria as discussed on p. 68-76.
   c. Test and service point requirements as discussed on p. 87-93.
   d. Line and cable requirements as discussed on p. 77-81.
   e. Mounting and packaging requirements as discussed on p. 54-61
   f. Fastener preferences and requirements as discussed on p. 62-67.

Independence requirements:
To the degree practicable, units and sub-units should be independent of each other, so that:
   a. Units are removable with minimum disturbance or removal of other units.
   b. Inputs to and outputs from each unit are kept to a minimum.
   c. There is a minimum of criss-crossing of signals between units.
   d. It is possible to check and/or adjust each unit separately.
   e. Connections between units are fail-safe, to prevent failure of one unit from causing failure of or damage to another.

Packaging requirements:

Combine detail parts into first order subassemblies, and subassemblies into larger units, so that:

a. Units satisfy the "Handling requirements," discussed on p. 60.
b. Parts or units are packaged with the greatest practicable density.
c. All parts in a unit contribute to a single and common function.
d. Each unit and sub-unit is removable and replaceable as a unit.
e. Units are ruggedized to withstand diverse environments and usages.

f. Where one or two parts of a unit are comparatively unreliable, these are mounted so they are removable from the exterior of the unit.
g. Sealed construction is provided for units requiring "clear room" assembly or repair at the depot or factory.
h. Modules which are subject to serious deterioration from moisture, vibration, etc., are encapsulated. (See "Disposable Modules," p. 124)

Testing, adjusting and servicing requirements:

Modules or other unitized assemblies should be designed so that:

a. Testing will accept or reject each unit on a go-no-go basis.
b. Tests of each unit allow valid, clear, and unequivocal decisions.
c. Minimal adjusting and servicing is required.
d. Critical or unnecessary adjustment or servicing is avoided.
e. Units require no, or minimal, calibration after replacement.
f. System realignment or harmonization is not required after replacement.
g. Factory or depot type adjustments:
   (1) Do not appear to the user in the field.
   (2) Are locked to prevent drift or change under the expected field-conditions.

Special applications:

Unitization is:

a. A prerequisite to encapsulation, sealing or potting.
b. A prerequisite to disposal-at-failure design.
c. Particularly necessary in miniaturized or design.
d. More useful in electronic than mechanical design, for the latter is typically very reliable, and easy to troubleshoot and repair.

e. Particularly desirable for components which are employed together in two or more systems or subsystems.
f. Practical even on a very large level, such as combining an engine and its associated transmission, carburetion system, ignition system, etc., into a package which is replaceable as a unit and susceptible to repair outside the vehicle.

DISPOSABLE MODULE REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "disposable module" here denotes any module designed to be thrown away, rather than repaired, after the first failure, assuming that the original diagnosis of failure is validated prior to disposal.

All decisions and requirements for disposable modules must be concurred with by the purchasing activity, and should be based on exhaustive and/or clearly decisive analyses which prove that:

a. Maintenance is either impractical or costs more than replacement.
b. The advantages given below outweigh the disadvantages.
c. Significant and favorable differences exist between the values of:
   (1) End costs of the disposable vs. the maintainable module.
   (2) Man-time, materials, tools, etc. necessary to maintain each.
   (3) Maintenance and supply programs as they differ in war and peace.
   (4) Supply, storage, handling, and procuring costs and problems.
   (5) Other costs and problems as determinable and applicable.

Advantages. Well-planned disposal at failure design usually results in:

a. Savings in repair time, tools, facilities and manpower.
b. Smaller, lighter, denser, simpler, more durable, and more reliabile design.
c. Fewer types of spares and a one-way supply system, at least for the item.
d. More concise and less difficult troubleshooting procedures.
e. Use of sealing and potting techniques which further improve reliability.
f. Improved standardization and interchangeability of modules and assemblies.

Disadvantages. Disposal at failure design can and often does result in:

a. Increased supply burdens, because the modules must always be on hand.
b. Reduction in failure and maintenance data to aid design improvement.
c. Excessive usage rates, through excessive and/or erroneous replacement.
d. Redesign problems and costs, because such modules cannot be modified.
e. Decline in personnel skills for lack of repair experience.
f. Degraded performance and/or reliability as a result of production efforts to keep modules economical enough to justify disposal.

DESIGN REQUIREMENTS:

Design, manufacture and install disposable modules so that:

a. They satisfy the discussion under "Unitization," on p. 122.
b. Expensive parts are not thrown away for failure of cheap parts.
c. Long life parts are not thrown away for failure of short life parts.
d. Low-cost and non-critical items are, in general, made disposable.
e. Throw-away modules are encapsulated wherever practical.
f. All encapsulated modules are designed for disposal at failure.
g. Modules costing $50 or less are disposable wherever practical.
h. Modules costing more than $50 are encapsulated as necessary to meet performance and reliability requirements.

i. The maintenance level of throw-away is clearly specified.
j. Test procedures to be applied before disposal are clearly specified, and provide clear and unequivocal results.
k. The identification plate or marking contains a statement which says: "DISPOSABLE AT FAILURE, see TO (number or other suitable reference to immediately available procedures)," to prevent repair attempts.

INTERCHANGEABILITY REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Interchangeable," here denotes the capability of any given part, unit or material to be substituted for a like part, unit or material, in accordance with the concepts and priorities under "Standardization," on p. 122.

"Functional interchangeability," exists if and to the degree that, two given parts, units or materials serve the same function. "Physical interchangeability," exists if and to the degree that, two given parts, units or materials can be mounted fastened, connected, etc., in the same manner and in the same places.

GENERAL REQUIREMENTS:

To achieve maximal maintainability, the Maintainability Engineer should seek to ensure that:

a. Functional interchangeability DOES exist where physical interchangeability is possible.
b. Physical interchangeability does NOT exist where functional interchangeability cannot be permitted. For positive means to prevent mis-mating or misapplication. (See "Connectors," p. 70)
c. Where complete interchangeability is not practical, parts or units are designed for functional interchangeability, and adaptors are provided to allow physical interchangeability, wherever practicable.

d. Unrealistic use of the terms, "or equivalent" or "interchangeable" are avoided, and known alternatives are listed instead.
e. Sufficient information is provided on identification plates and within related job instructions so the user can adequately judge whether two similar parts are interchangeable.

f. Modified units do not unnecessarily change the manner of mounting, connecting, locating, etc. of the class of units.
g. Differences in size, shape, mounting, etc. which do not reflect functional properties of the part or unit are avoided.

h. Complete interchangeability is provided for all items or units which:
   (1) Are intended to be identical--i.e., good quality control.
   (2) Are identified as being interchangeable with each other.
   (3) Have the same manufacturer's number or other identification.
   (4) Serve the same function in different applications, particularly if the mortality rates are high, such as for gasoline engine parts, wheels, resistors and fuses of the same value, etc.

To facilitate interchangeability, design equipment so that:

a. Mounting holes and brackets accomodate units of different makes, such as engines of the same type and horsepower, built by different manufacturers.
b. Identical parts are used wherever possible in similar equipment or a series of a given type, such as using the same bore and stroke for a series of internal combustion engines.
c. Parts, fasteners, connectors, lines and cables, etc., are standardized throughout the system and, particularly, from unit to unit within the system.

ENVIRONMENTAL REQUIREMENTS

DECISION FACTORS:

Explanation: The term, "Environmental," is here taken to include some aspects of the total system which, though external to the equipment, can affect the task performance of the maintenance man. These aspects are: temperature, humidity, noise, vibration, illumination and radiation.

Intent: It is not the intent of this Guide to cover all of the facets of these environmental aspects, because:

a. Many of these aspects are extremely critical to health and safety and must be considered specific to the system.
b. Some of these aspects are subject to change, since new information, as it is being found, is changing the requirements and any decisions should be based on the latest findings.
c. The environmental parameters interact with each other in complex ways which cannot be adequately described in a short space.
d. An adequate evaluation of system specific environmental factors and/or requirements for protective equipment, safety devices, etc. requires thorough analysis by qualified professionals in the specific field.

Rather, this section will only attempt to:

a. Call attention to factors significant to maintainability.
b. Provide design limits for fairly standard environmental conditions.
c. Call attention to the need for expert consultation when environmental factors deviate from design limits.

GENERAL REQUIREMENTS:

The effects of deviations from specified tolerable conditions should be anticipated and planned for in design to the degree that such deviations may result in:

a. Requirements for protective clothing, devices, etc., which affect the mobility, reach, work space, access size, etc., for efficient and effective maintenance.
b. Reduced reliability, which requires a higher degree of maintainability to ensure overall system availability.
c. Border-line conditions which, though they have little or no direct effect on equipment, may seriously impair the ability of the technician to work effectively.
d. Conditions which, for the above or other reasons, contribute to longer maintenance time, or maintenance errors, oversights, etc. which are detrimental to system availability and/or performance.

The Maintainability Engineer should concern himself with the effects on maintenance of three primary sets of environmental factors:

a. The natural or geographic environment as discussed below.
b. Specific subsystem effects, materials, or elements such as toxic fuels, LOX loading procedures and problems, single sources of vibration, high pressure lines, etc.
c. The accumulative, conflicting or interactive effects of environmental factors in the full and final system configuration.

REQUIRED EQUIPMENT OPERATING CONDITIONS: (See Ref. 5 and 48)

Unless otherwise specified, unsheltered equipment for outdoor use should be designed to be inherently capable of satisfactory operation under the following environmental conditions, according to the area in which it is to be used.

Temperature:

a. Standard Area:
   (1) Operating: -29 to 52° C (-20 to 125° F)
   (2) Non-operating: -54 to 54° C (-65 to 130° F)
b. Cold weather area:
   (1) Operating: -40° C (-40° F) if operator is unsheltered.
   (2) Operating: -54° C (-65° F) if operator is sheltered.
   (3) Non-operating: -62° C (-80° F) for 3 days and achieve rated capacity after 30 minutes pre-heating and warm-up.
c. Desert and tropical areas:
   (1) Operating: 52° C (125° F).
   (2) Non-operating: 71° C (160° F) for 4 hours per day indefinitely.

Humidity:

a. Operating: Up to 100% at 37° C (100° F) including condensation.
b. Non-operating: Up to 100% including condensation.

Solar radiation:

Endure a solar intensity of 360 BTU per square foot, per hour for a period of 4 hours at 52° C (125° F).

Wind:

Withstand wind pressures up to 30 pounds per square foot of projected surface, either empty or under load.

Barometric pressure:

a. Operating: from 30 to 16.8 inches of mercury (0-15,000 ft.).
b. Non-operating: from 30 to 5.54 inches of mercury (0-40,000 ft.).

Other conditions:

a. Salt atmosphere, as encountered in coastal regions or ocean transport.
b. Sand and dust, as encountered in desert regions.
c. Insects and fungi, as encountered in the tropics.
d. Ice load, as specified in the detailed specifications.
e. Rainfall, as specified in the detailed specifications.

Reliability:

The reliability of equipment will be greatly enhanced if the designer assumes that the equipment will be used at both extremes of the various environmental conditions, and provides built-in features to shed moisture, resist rust, resist fungi, etc.

Maintainability:

The maintainability of equipment will be greatly enhanced if the designer assumes that the equipment will be maintained at the extremes of the various environmental conditions, and provides built-in features to facilitate such maintenance. (See "Shelter requirements," p. 103)

NOISE REQUIREMENTS:

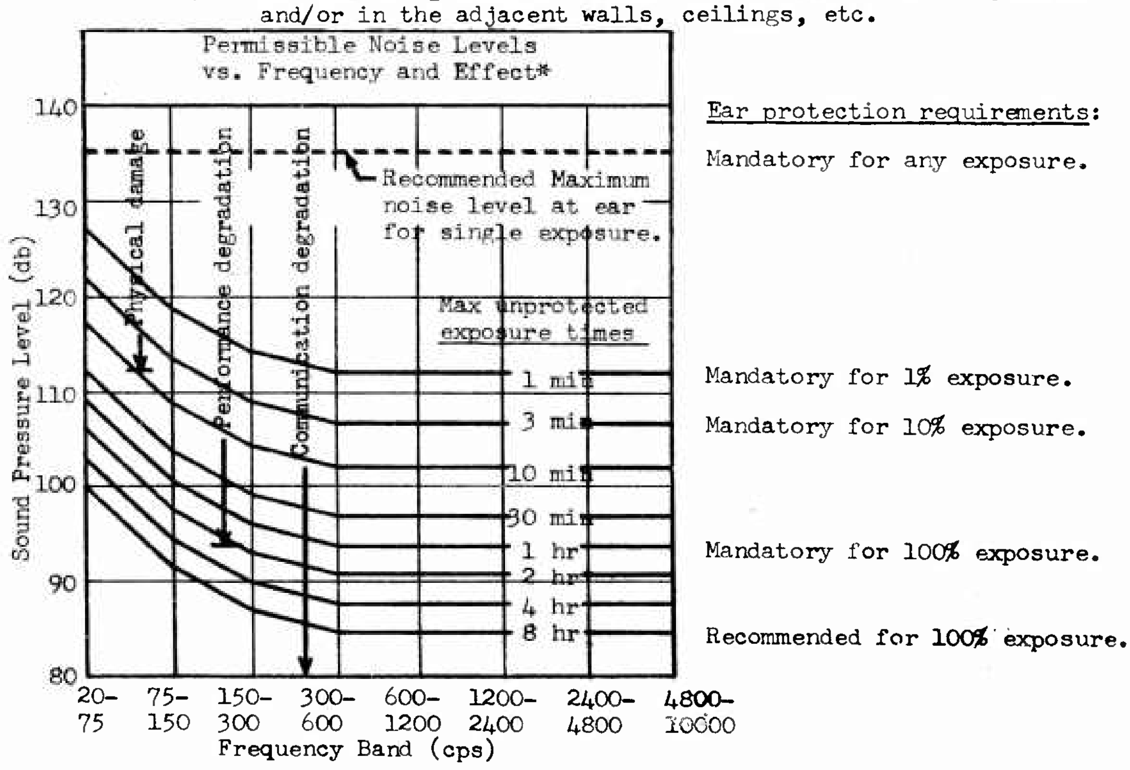
Noise seldom affects equipment, except through concomitant vibration; but it can result in a performance decrement on the part of maintenance personnel and may constitute a health hazard. For instance, high noise levels may:

a. Impair hearing, cause internal injuries, or even cause death.
b. Contribute to increased boredom, fatigue, nervousness and irritability.
c. Hinder voice communication and the transmission of audio signals.

As a general rule, noise should be minimized wherever practicable in design and, at worst, should never exceed the limits prescribed in the graph below. Where the cummulative noise level approaches these limits, the Maintainability Engineer can help meet the requirements for tolerable noise levels by cooperating with:

a. Safety and Human Engineering Groups, to evaluate noise problems and/or provide personnel with protective devices in the form of ear plugs, special helmets, or other sound attenuating devices.

b. Equipment design groups, to reduce noise in the equipment through provisions for:
   (1) Vibration mounts or better balance for the equipment.
   (2) Enclosures for noise producing sources.
   (3) Mufflers or baffles on such parts as engine exhausts, vents in high pressure systems, etc.
   (4) Sound absorbing material between the noise source and personnel and/or in the adjacent walls, ceilings, etc.



* Adapted with permission from Ref. 49.

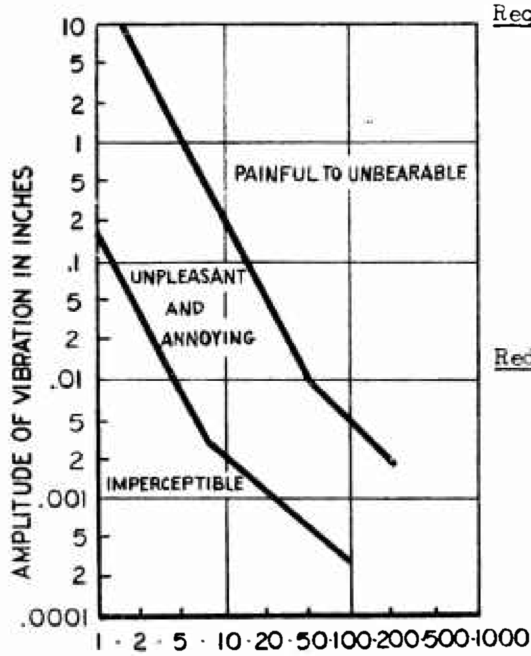
VIBRATION REQUIREMENTS:

Both amplitude and frequency must be considered in evaluating the level of vibration, its effects, and/or requirements for protective or preventive devices or measures.

Effects:

The effects of vibration on maintainability are felt in two major ways:

a. Equipment is much more likely to require maintenance when it is subject to vibration, because this increases wear, loosens connectors, etc.
b. Performance of the technician is adversely effected to the degree that vibration:
   (1) Can, at high levels, cause critical bodily damage.
   (2) Makes dials and lettering difficult to read.
   (3) Makes tools, controls and other objects difficult to manipulate.
   (4) Contributes to increased fatigue, nervousness and irritability, and, thus, to maintenance errors, oversights, etc.



Requirements:

The graph at left illustrates critical limits for the effects of vibration on the human. As a general rule, vibration should:

a. Be minimized wherever practicable in design.
b. Be kept below the "unpleasant and annoying" range wherever practicable.
c. Never be allowed to approach the "painful to unbearable" range.
d. Be measured and analyzed by biomedical personnel.

Reduction:

Vibration can be reduced and controlled by:

a. Isolating equipment from vibration sources by shock mountings, fluid couplings, etc.
b. Providing proper balance of rotating elements of equipment.
c. Providing damping materials or cushioned seats for standing or seated personnel. (Personnel are most affected by vibrations transmitted through the longitudinal axis of the body, head to toe, regardless of body position.)

* Adapted with permission from Ref. 45.

ILLUMINATION REQUIREMENTS: (See Ref. 28)
Sufficient lighting should be provided in all work areas to allow task performance in accordance with the general conditions and requirements provided below.

Recommended Illumination Intensities
(in foot-candles at the work point)

Light level	Task conditions	Type of lighting
100 or more	Very difficult and prolonged visual tasks with objects of low brightness contrast; high speed and extreme accuracy required.	Supplementary; Special fixtures such as desk lamps
50 or more	Small detail, fair contrast, close work, speed not essential.	Supplementary
25 or more	Prolonged reading, assembly, general office, ordinary bench, or laboratory work.	Local lighting; Ceiling fixtures directly overhead
10 or more	Occasional reading, washrooms, power plants, waiting rooms, and kitchens.	General lighting
5 or more	No detail vision, stairways, or supply warehouses.	General or supplementary lighting

Distribution and brightness contrast requirements:
Lighting should be arranged to provide an equal level of illumination over the entire working area. Since this is usually impossible, the following requirements should be met to approximate the ideal.

Brightness ratios. Maximum allowable brightness ratios are as follows:

Ratio	Condition
5:1	Between task and adjacent surroundings.
20:1	Between task and remote surfaces.
40:1	Between light source (or sky) and surfaces adjacent to it.
80:1	Between the immediate work area and remainder of the environment.

Glare problems. Avoid glare (which slows work and produces fatigue) by:
a. Using surfaces and paints which diffuse rather than reflect light.
b. Avoiding bright surfaces within the working visual field.
c. Avoiding bright light sources within 60° of the central visual field.
d. Placing lights high and directly above the work area.
e. Using indirect lighting wherever possible.
f. Using diffused lighting where possible, spaced high and close together.
g. Arranging light sources to avoid equal lighting and viewing angles.
h. Providing shields, hoods and visors to reduce or prevent glare.
i. Using numerous low intensity sources rather than a few intense ones.

Display and control lighting:
a. Use low intensity red lighting where dark adaptation is required.
b. Use auditory signals where perception of visual displays is difficult.
c. Code controls by shape and spacing when they cannot be adequately seen.
d. Use self-illuminated indicators or back-lighting where the quality or intensity of light would otherwise hinder color discrimination.
e. Provide auxiliary lighting for all displays in trailers or consoles; this lighting system should be independent from the prime system.

f. Limit indicator colors to red, green, blue, amber, yellow, and white to minimize misinterpretation.
g. Provide at least the following brightness values for displays and controls:
   (1) .01 foot-lamberts for coarse details; e.g., activating switches.
   (2) .05 foot-lamberts for precise work; e.g., reading small dials.

Safety requirements:
a. Use explosion-proof lamps near fuels or other explosion or fire hazards.
b. Provide emergency lighting in the event of power failure in critical areas.
c. Provide extensions from ground support equipment or other sources so the technician can have light when there is no power on the prime unit.

TEMPERATURE AND HUMIDITY REQUIREMENTS:

Temperature and humidity affect both the need for maintenance and the ability to perform maintenance.

In general, the requirements for temperature and humidity control of equipment, in order to achieve and maintain operability, are a design and reliability function. The requirements for such control are:
a. Indicated by the operating conditions discussed on p. 127.
b. Generally equipment specific, as determined by reliability requirements.
c. Adequately documented in Air Force requirements and specifications, such as HIAD, HIGED, or MIL-E-16400. (Ref. 24, 23, 12)

But the Maintainability Engineer should work with design groups to ensure that:
a. The environmental conditions in which the maintenance technician must work are within tolerable limits, as provided in the graph below.
b. Maintenance requirements, as a function of temperature related design or environmental control, are minimized in accordance with relevant topics within this Guide--e.g., fasteners, mounting, covers, cases, etc.
c. Design adequately allows for and takes into consideration the effects of temperature upon maintenance.

Requirements:

The Maintainability Engineer should specifically ensure that:
a. Sufficient access or internal workspace is provided to allow for protective equipment and/or clothing, where personnel must maintain equipment that can cause burns, freezing, or discomfort:
   (1) See "Access Requirements," p. 42-46
   (2) See "Work Space Requirements," p. 47-50.

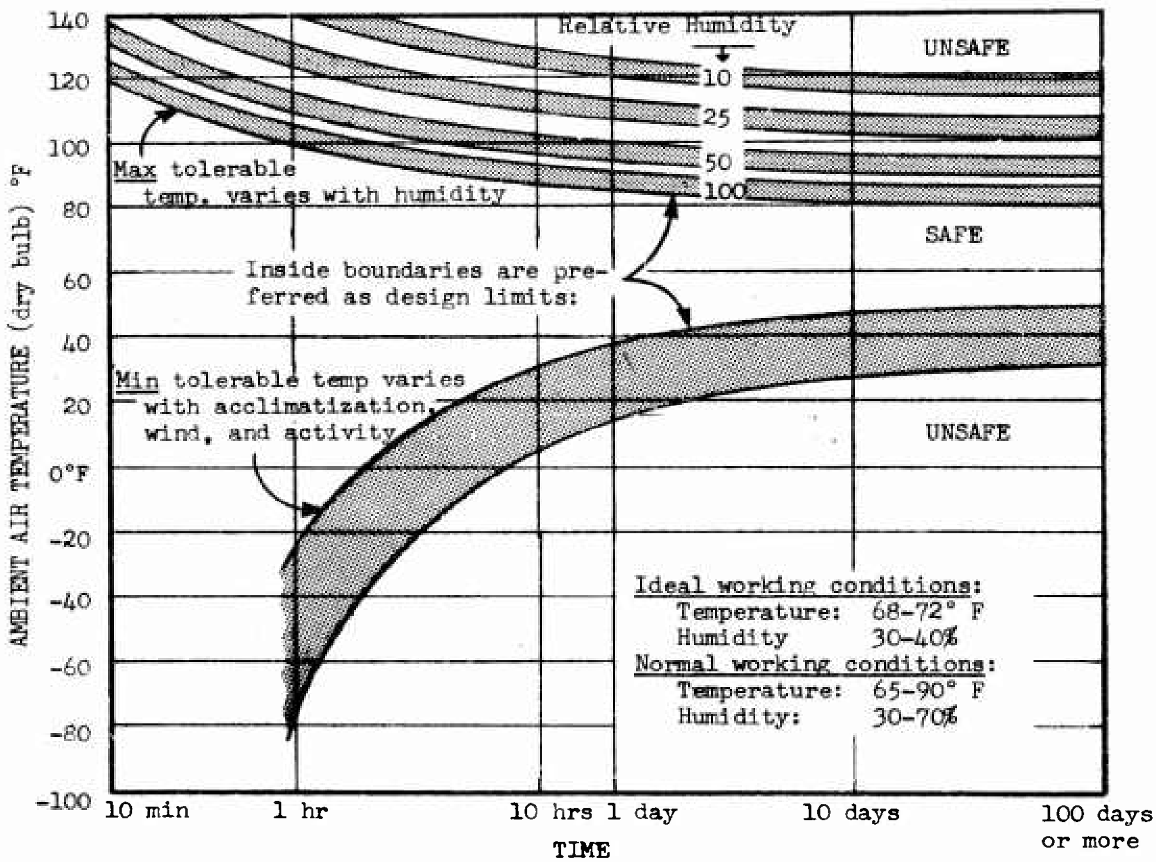
b. Those controls, handles, tools, or other objects which must be manipulated are either located in areas in which normal temperatures are maintained or are designed in accordance with the clearance requirements for protective clothing.
   (1) See "Handle Requirements," p. 52-53.
   (2) See "Hand Clearances," p. 44.

c. Provisions are made for temperature stabilization of those pieces of equipment which, if handled while in extreme temperature conditions, are likely to suffer damage--e.g., coaxial cables when cold, etc.
   (1) See "Mounting and Packaging Requirements," p. 54-61.
   (2) See "Protection and Safety Requirements," p. 99.

d. Warning labels are prominently displayed on the face of equipment to provide indications of the above conditions as necessary to prevent injury to personnel or damage to equipment.
   (1) See "Coding and Labeling," p. 58.
   (2) See "Protection and Safety Requirements," p. 99.

e. The environment within which the maintenance technician must work does not exceed the tolerance limits provided in the graph below and, where practicable, falls within "ideal" or "normal" ranges.

APPROXIMATE HUMAN TIME-TOLERANCES*
(Assuming Optimum Clothing)



* Adapted with permission from Ref. 49.

RADIATION:

Radiation is a problem that becomes increasingly important as new uses and handling methods come into being. The health hazards of radiation are fairly well known and extremely dangerous.

Protective devices, and determination of permissible dosages and rate, change as new data are determined. The Maintainability Engineer must consult with biomedical personnel and Atomic Energy Commission information to determine latest information on acceptable dosage and rate, as well as on acceptable, protective devices.

The danger of presenting information here that is current at this time, is that someone might act on the basis of this information at a time when it has become obsolete.

PERSONNEL FACTORS

DECISION FACTORS:

The realm of "personnel factors" is virtually inexhaustible. But design for maintainability should be concerned only with those factors and data which are directly and immediately applicable to design. The difficulty in deciding which factors are relevant can be largely resolved by basing design for maintainability upon the average Air Force maintenance man. The data below provide both justification for and the major implications of this phrase.

Despite of his limitations, the average airman is very capable, but his capability depends, in the main, upon the extent to which his limitations and attributes are taken into consideration in equipment design.

GENERAL DATA:

NOTE: These charts provide percentages of airmen in the categories indicated. Adapted from Ref. 51.

Age Yrs	%	Service Time Yrs	%	Education Grade	%	Intelligence Category	%
Older	29.1	More	15.5	Higher	.7	I	13.25
25-26	8.0	12	5.7	16th	3.7	II	29.38
23-24	11.2	10	6.5	14th	9.6	III	43.23
21-22	20.2	8	8.7	12th	56.9	IV	14.14
19-20	22.1	6	11.2	10th	22.6		
Younger	8.6	4	29.1	8th	4.5		
		2	13.5	Lower	2.0		
		1	9.9				

Average values and comparisons:

	Age	Service Time	Education	Intelligence
The average airman:	22 yrs old	3-4 yrs	12th Grade	III
Av. airline mechanic:	28-30	8-10	13-14th	III+
Av. R&D designer:	30-35	5-10	16-17th	II

Supplementary information:

The average Air Force maintenance man is:

a. An Airman First Class on his first 4-year enlistment.

b. Inexperienced; he had no work experience prior to entering service.

c. From a small town or farm west of the Mississippi; his occupation, education, recreation and cultural patterns are rural.

He should not be required routinely to:

a. Read at higher than the 9th grade reading level.

b. Perform arithmetic calculations, even simple addition or subtraction.

c. Consolidate or integrate information from multiple sources.

d. Collect, process or report any unnecessary or complicated data.

e. Post data from one form to another or to keep any permanent records.

NOTE: The error rates for the above operations, when performed at the weapon site as part of other maintenance duties, tend to be prohibitive.

His military training totals 19 weeks--i.e., 6 weeks basic training, 6 weeks specialty training, and 7 weeks weapon system training.

His monthly cost is about $336 (including $160 base pay, $77 housing, $73 food and supplies, $26 clothing, medical care, insurance, etc.)

He is on the job 201 days a year (excluding 30 days leave, 96 weekend days, 26 days extra duty, and 12 days sick, holidays, pass, etc.)

His time cost is about $2.85 per hour or $22.78 per day, for time actually spent on maintenance, if training time is prorated over 4 years.

For manning purposes, then, 5 men are required to fill a full-time position 3 shifts a day, 365 days a year, assuming no extra duty.

BODY DIMENSIONS

DECISION FACTORS:

The anthropometric data on the following pages are intended to provide a basis for design decisions not specifically covered herein. Use of these data must take the following into consideration:

a. The nature, frequency, and difficulty of the related tasks.
b. The position of the body during performance of these tasks.
c. Mobility or flexibility requirements imposed by the tasks.
d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc.
e. Increments in the design-critical dimensions imposed by protective garments, packages, lines, padding, etc.

For practical design purposes, the required increments can be determined by the following methods (listed in order of preference):

1. Obtaining such information from the garment or device manufacturer.
2. Experimentally determining the required data in accordance with good sampling, statistical and experimental procedures.
3. Approximating design-critical dimensions by fitting subjects representing appropriate percentiles and obtaining the differences between nude and fitted dimensions. These differences (increments) may ordinarily be treated as constants.
4. Measuring appropriate thicknesses or other critical values of the garment or device and adding these, as constants, to the anthropometric values.

GENERAL RULES FOR USE OF DATA:

Inclusive dimensions (passageways, accesses, safety clearances, etc.) which must accommodate or allow passage of the body should be based upon the 95th percentile values.

Exclusive dimensions (reaching distance, interstices of protective screens, control movement, etc.) which must prohibit or are limited by extension of the body should be based upon the 5th percentile values.

Fixed features (controls, displays, test points, handrails, etc.) should be located in accordance with appropriate mean values to provide utility to the full range of anthropometric variation.

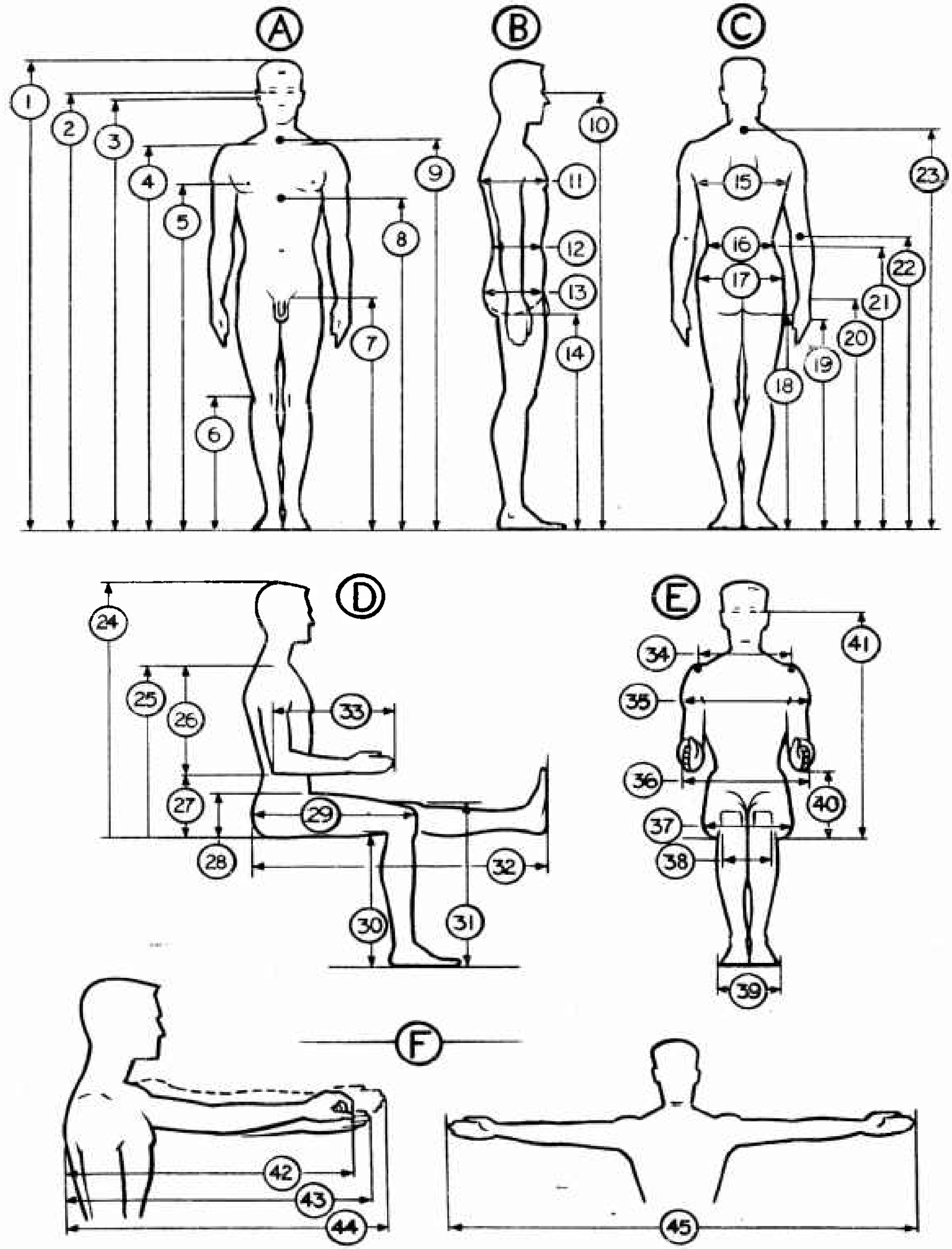
Adjustable features (seats, safety goggles, belts, controls, etc.) should be adjustable across the range from 1st to 99th percentile in each critical dimension (5th to 95th percentiles may be used with customer approval).

Ambiguous, safety critical or comfort critical design decisions involving use of these data should be coordinated with Human Factor Specialists.

Tradeoffs. Percentile increments should not be used as design tradeoffs. Although these seem to merely reduce the percentage of the population that can do the job, this reduction is considerably less important to system maintainability than the fact that the consequent increase in difficulty or frustration is likely to result in maintenance errors or oversights. Tradeoffs may be made among alternative tasks or body positions, but the final design should generally accommodate the 5th to 95th percentiles.

NOTE: Except where noted in the following pages (134-141):

a. All values are in inches.
b. The symbol, (s), indicates a measure taken in the sitting position.
c. Clothing increments were adapted from Ref. 20 and 32.
d. The terminology and data were adapted from WADC TR 52-321 (Ref. 27).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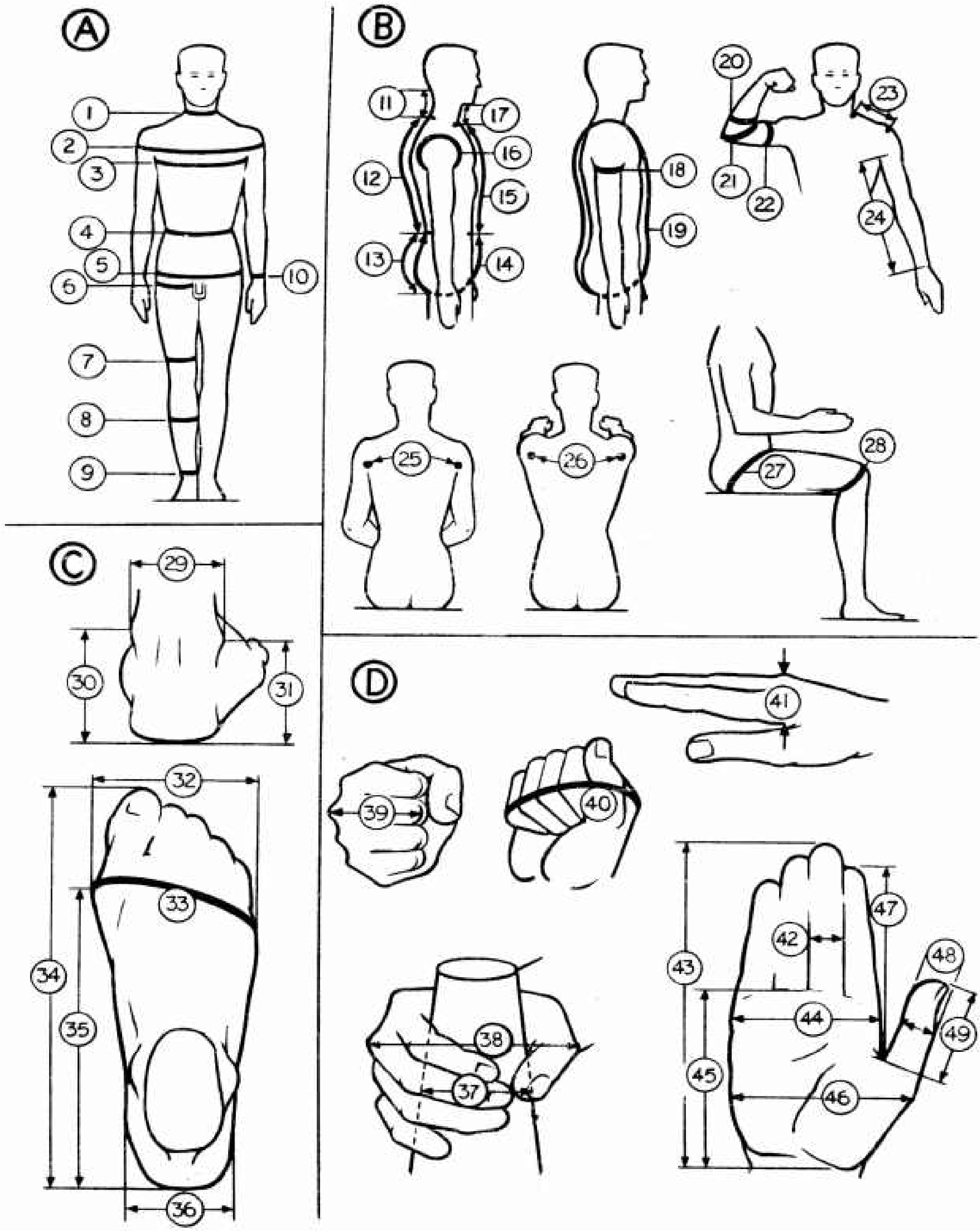
NOTE: Weight in pounds, all other values in inches.

		Design Values (Percentiles)				Distribution Parameters		Hvy Winter Clothing Increment
		1st	5th	95th	99th	Mean	S.D.	
	Weight (in pounds)	123.1	132.5	200.8	215.9	163.66	20.86	
A								
1.	Stature (Int. Canthus)	63.5	65.2	73.1	74.9	69.11	2.44	1.9
2.	Eye Height	59.2	60.8	68.6	70.3	64.69	2.38	
3.	Ear Height (Tragion)	58.4	60.0	67.8	69.6	63.2	2.39	
4.	Shoulder Height (Acrom.)	51.2	52.8	60.2	61.9	56.50	2.28	
5.	Nipple Height	45.6	47.0	53.9	55.3	50.41	2.08	
6.	Kneecap Height (Patella)	17.9	18.4	21.9	22.7	20.22	1.03	
7.	Penale Height	30.6	31.6	37.4	38.7	34.52	1.75	
8.	Substernale Height	44.0	45.6	52.1	53.5	48.71	2.02	
9.	Suprasternale Height	51.3	52.7	59.9	61.5	56.28	2.19	
B								
10.	Nasal Root Height	59.4	61.0	68.9	70.7	64.95	2.39	
11.	Chest Depth	7.6	8.0	10.4	11.1	9.06	.75	1.4
12.	Waist Depth	6.3	6.7	9.5	10.3	7.94	.88	1.4
13.	Buttock Depth	7.2	7.6	10.2	10.9	8.81	.82	
14.	Crotch Height (Inseam)	29.3	30.4	35.7	37.0	32.83	1.73	
C								
15.	Chest Breadth	10.4	10.8	13.4	14.1	12.03	.80	0.6
16.	Waist Breadth	8.9	9.4	12.3	13.3	10.66	.94	
17.	Hip Breadth	11.3	12.1	14.4	15.2	13.17	.73	1.3
18.	Gluteal Furrow Height	27.9	29.0	34.3	35.5	31.57	1.62	
19.	Knuckle Height	26.7	27.7	32.4	33.5	30.04	1.45	
20.	Wrist Height	30.1	31.0	36.1	37.1	33.52	1.54	
21.	Waist Height	37.7	39.1	45.0	46.4	42.02	1.81	
22.	Elbow Height (Radiale)	39.5	40.6	46.4	47.7	43.50	1.77	
23.	Cervicale Height	53.7	55.3	62.9	64.6	59.08	2.31	
D								
24.	Sitting Height	32.9	33.8	38.0	38.9	35.94	1.29	0.6
25.	Shoulder Ht. (Acrom.)(s)	20.6	21.3	25.1	25.8	23.26	1.14	0.6
26.	Shoulder Elbow Length	12.8	13.2	15.4	15.9	14.32	.69	0.3
27.	Waist Height, (s)	7.4	7.9	10.4	10.9	9.24	.76	
28.	Thigh Clearance Ht. (s)	4.5	4.8	6.5	6.8	5.61	.52	
29.	Buttock-Knee Length (s)	21.2	21.9	25.4	26.2	23.62	1.06	0.5
30.	Back of Knee Height (s)	15.3	15.7	18.2	18.8	16.97	.77	
31.	Knee Height (s)	19.5	20.1	23.3	24.0	21.67	.99	1.8
32.	Buttock-Leg Length	38.2	39.4	46.1	47.7	42.70	2.04	
33.	Forearm-Hand Length	17.0	17.6	20.2	20.7	18.86	.81	
E								
34.	Biacromial Diameter	14.0	14.6	16.9	17.4	15.75	.74	
35.	Shoulder Breadth	15.9	16.5	19.4	20.1	17.88	.91	0.7
36.	Elbow-to-Elbow Breadth	14.5	15.2	19.8	20.9	17.28	1.42	4.4
37.	Hip Breadth, Sitting	12.2	12.7	15.4	16.2	13.97	.87	
38.	Knee-to-Knee Breadth	7.0	7.2	8.8	9.4	7.93	.52	2.5
39.	Breadth of Both Feet	6.8	7.0	8.2	8.7	7.6	.38	2.4
40.	Elbow Rest Height	6.6	7.4	10.8	11.5	9.12	1.04	
41.	Eye Ht. (Int. Canthus)	28.5	29.4	33.5	34.4	31.47	1.27	0.4
F								
42.	Functional Reach	28.8	29.7	35.0	36.4	32.33	1.63	0.4
43.	Arm Reach From Wall	30.9	31.9	37.3	38.6	34.59	1.65	0.4
44.	Maximum Reach From Wall	34.1	35.4	41.7	43.2	38.59	1.90	
45.	Span	63.9	65.9	75.6	77.6	70.80	2.94	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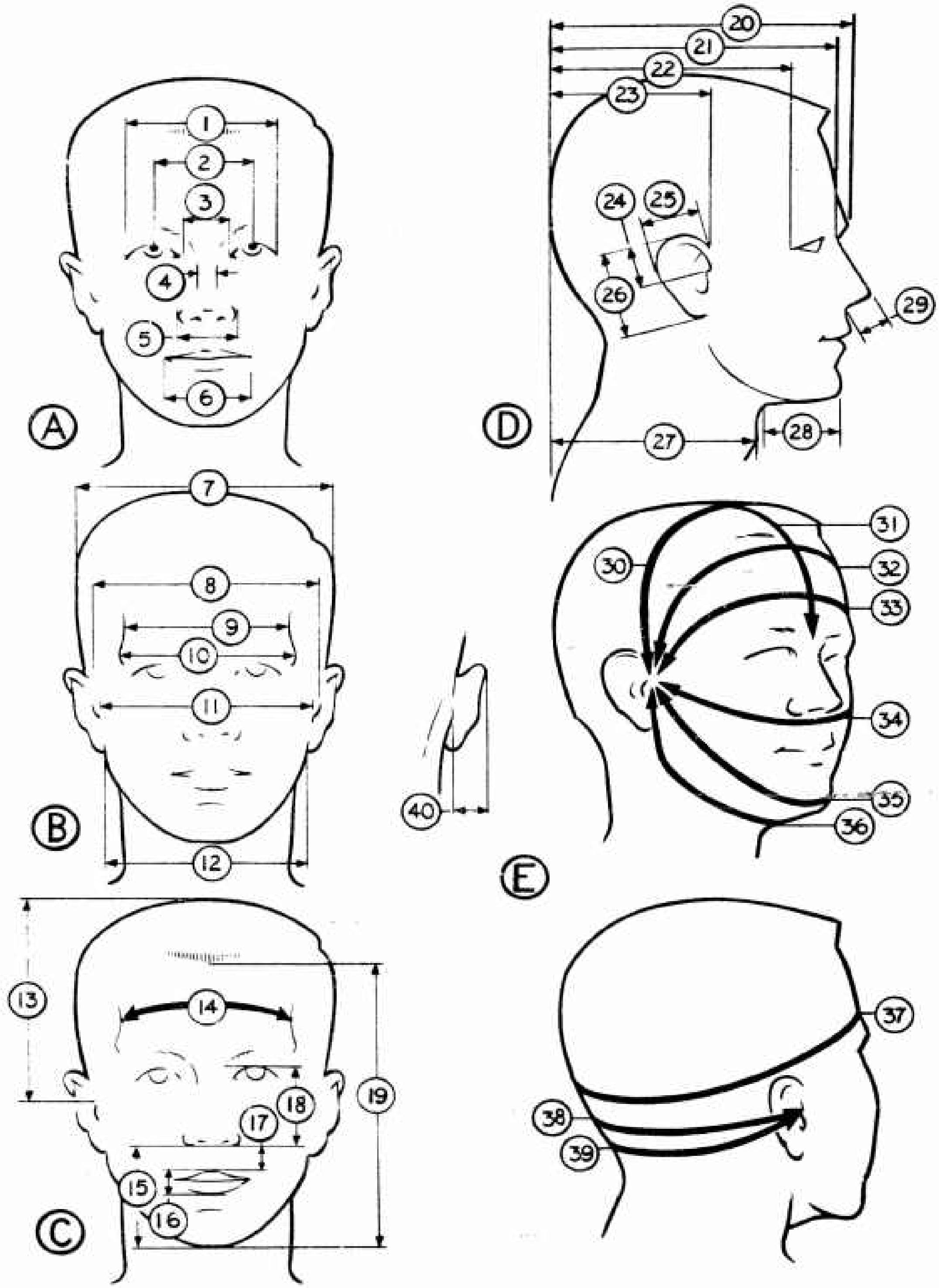
NOTE: All values in inches.
* Data from Ref. 2.

		Design Values (Percentiles)				Distribution Parameters		Hvy Winter Clothing
		1st	5th	95th	99th	Mean	S.D.	Increment
A	BODY CIRCUMFERENCES:							
1.	Neck Circumference	13.3	13.8	16.2	16.8	14.96	.74	
2.	Shoulder Circumference	40.2	41.6	49.4	51.5	45.25	2.43	
3.	Chest Circumference	33.7	35.1	43.2	44.8	38.80	2.45	9.1
4.	Waist Circumference	26.5	27.8	37.5	40.1	32.04	3.02	
5.	Buttock Circumference	33.0	34.3	41.8	43.5	37.78	2.29	
6.	Thigh Circumference	18.3	19.6	25.3	26.4	22.39	1.74	
7.	Lower Thigh Circum.	14.2	15.1	19.6	20.9	17.33	1.41	
8.	Calf Circumference	12.2	12.9	16.0	16.7	14.40	.96	6.0
9.	Ankle Circumference	7.8	8.1	9.8	10.5	8.93	.57	
10.	Wrist Circumference	6.0	6.3	7.5	7.8	6.85	.40	
B	CLOTHING DIMENSIONS:							
11.	Posterior Neck Length	2.3	2.7	4.7	5.2	3.64	.61	
12.	Waist Back	14.8	16.1	19.4	20.2	17.72	1.07	
13.	Gluteal Arc	9.7	10.4	13.1	14.8	11.71	.92	
14.	Crotch Length	23.7	25.1	31.6	33.5	28.20	2.00	
15.	Waist Front	12.3	13.5	17.0	18.1	15.24	1.12	
16.	Scye Circumference	15.1	16.1	20.5	21.8	18.09	1.38	
17.	Anterior Neck Length	1.8	2.3	4.4	4.9	3.40	.64	
18.	Axillary Arm Circum.	10.2	10.9	14.4	15.2	12.54	1.10	
19.	Vertical Trunk Circum.	58.3	60.2	69.7	71.7	64.81	2.88	
20.	Lower Arm Circum. (flexed)	9.9	10.4	12.7	13.3	11.50	.73	
21.	Elbow Circum. (flexed)	10.7	11.1	13.6	14.3	12.26	.80	
22.	Biceps Circum. (flexed)	10.5	11.2	14.6	15.4	12.79	1.07	
23.	Shoulder Length	5.5	5.9	7.7	8.1	6.77	.56	
24.	Sleeve Inseam	17.1	18.0	21.7	22.6	19.83	1.14	
25.	Interscye	16.3	17.3	22.0	22.9	19.62	1.40	
26.	Interscye Maximum	19.8	20.7	25.1	26.0	22.85	1.33	
27.	Buttock Circum., Sitting	36.1	37.4	46.7	49.3	41.74	2.82	
28.	Knee Circum., Sitting	13.5	14.0	16.9	17.7	15.39	.92	
C	FOOT DIMENSIONS:							
29.	Ankle Breadth	2.61	2.70	3.19	3.32	2.95	.15	
30.	Ankle Height (Medial)	3.0	3.1	3.8	4.0	3.45	.21	
31.	Ankle Height (Lateral)	2.2	2.4	3.1	3.3	2.73	.22	
32.	Foot Breadth	3.40	3.50	4.10	4.36	3.80	.19	1.2
33.	Ball of Foot Circum.	8.6	8.9	10.4	10.8	9.65	.48	
34.	Foot Length	9.5	9.8	11.3	11.6	10.50	.45	2.7
35.	Instep Length	6.9	7.1	8.2	8.4	7.64	.34	
36.	Heel Breadth	2.30	2.40	2.87	3.01	2.64	.15	
D	HAND DIMENSIONS:							
37.	Grip Diameter (Inside)	1.52	1.62	2.05	2.16	1.90	.14	
38.	Grip Diameter (Outside)	3.58	3.72	4.44	4.57	4.09	.21	
39.	First Phalanx III Length	2.40	2.49	2.85	2.95	2.67	.12	
40.	Fist Circumference	10.2	10.7	12.4	12.	11.56	.57	
41.	Thickness at Metacarp.III	1.00	1.05	1.28	1.35	1.17	.07	
42.	Finger Diameter III	.77	.79	.93	.96	.86	.05	
43.	Hand Length	6.7	6.9	8.0	8.3	7.49	.34	0.3
44.	Hand Breadth at Metacarp.	3.12	3.22	3.74	3.86	3.48	.16	
45.	Palm Length	3.77	3.89	4.60	4.74	4.24	.21	
46.	Hand Breadth at Thumb	3.59	3.73	4.42	4.57	4.07	.21	0.4
47.	Digit to Crotch Height*	3.79	3.99	5.01	5.21	4.50	.31	
48.	Thumb Thickness *	.66	.69	.84	.87	.76	.05	
49.	Thumb Length *	1.92	2.03	2.61	2.72	2.32	.17	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NOTE: All values in inches.		Design Values (Percentiles) 1st	5th	95th	99th	Distribution Parameters Mean	S.D.	Hvy Winter Clothing Increment
1.	Biocular Diameter	3.38	3.48	4.06	4.19	3.78	.17	
2.	Interpupillary Distance	2.19	2.27	2.74	2.84	2.49	.14	
3.	Interocular Diameter	1.03	1.09	1.42	1.50	1.25	.10	
4.	Nasal Root Breadth	.42	.48	.74	.81	.61	.08	
5.	Nose Breadth	1.09	1.16	1.49	1.58	1.31	.11	
6.	Lip Length (Bichelion Dia.)	1.72	1.81	2.27	2.38	2.03	.14	
7.	Head Breadth	5.61	5.74	6.40	6.56	6.07	.20	0.4
8.	Bitragion Diameter	5.1	5.3	5.9	6.1	5.60	.21	
9.	Minimum Frontal Diameter	3.88	4.04	4.68	4.80	4.35	.19	
10.	Maximum Frontal Diameter	4.26	4.39	5.05	5.20	4.71	.20	
11.	Bizygomatic Diameter	5.07	5.21	5.88	6.02	5.55	.20	
12.	Bigonial Diameter	3.8	3.9	4.6	4.8	4.27	.22	
13.	Head Ht. (Tragion-Vertex)	4.4	4.6	5.6	5.8	5.11	.30	
14.	Minimum Frontal Arc	4.5	4.8	6.1	6.3	5.44	.40	
15.	Menton-Subnasale Length	2.05	2.19	3.07	3.28	2.63	.27	
16.	Lip-to-Lip Distance	.35	.44	.83	.94	.64	.12	
17.	Philtrum Length	.48	.54	.98	1.09	.77	.14	
18.	Nose Length	1.69	1.79	2.23	2.33	2.01	.14	
19.	Menton-Crinion Length	6.6	6.8	8.0	8.2	7.36	.36	
20.	Head Length	7.2	7.3	8.2	8.3	7.76	.25	0.4
21.	Nasal Root to Wall	7.0	7.2	8.3	8.5	7.75	.34	
22.	External Canthus to Wall	6.0	6.2	7.3	7.5	6.78	.32	
23.	Tragion to Wall	3.4	3.5	4.5	4.8	4.03	.30	
24.	Ear Length above Tragion	.92	.99	1.35	1.42	1.17	.11	
25.	Ear Breadth	1.20	1.27	1.61	1.70	1.44	.11	
26.	Ear Length	2.08	2.21	2.73	2.85	2.47	.16	
27.	Larynx to Wall	5.8	6.2	7.7	8.0	6.95	.47	
28.	Menton Projection	1.3	1.5	2.3	2.5	1.88	.26	
29.	Nose Protusion	.63	.72	1.08	1.17	.89	.11	
30.	Bitragion-Coronal Arc	12.7	13.0	14.7	15.1	13.83	.51	
31.	Sagittal Arc	13.6	14.1	16.0	16.5	15.07	.61	
32.	Bitragion-Crinion Arc	12.0	12.3	14.0	14.4	13.10	.53	
33.	Min. Bitragion-Frontal Arc	11.1	11.4	12.8	13.1	12.05	.44	
34.	Bitragion-Subnasale Arc	10.5	10.7	12.2	12.4	11.45	.43	
35.	Bitragion-Menton Arc	11.6	12.0	13.6	14.0	12.78	.50	
36.	Bitragion-Submandibular	10.7	11.1	13.1	13.7	12.08	.62	
37.	Head Circumference	21.0	21.5	23.5	24.3	22.47	.62	1.7
38.	Bitragion-Inion Arc	10.5	10.8	12.6	13.0	11.62	.55	
39.	Bitragion-Posterior Arc	9.7	10.0	11.5	11.9	10.71	.48	
40.	Ear Protrusion	.55	.63	1.10	1.23	.84	.14	

HUMAN STRENGTH

DECISION FACTORS:

Design decisions which assume the application of human muscular force must take the following factors into consideration:

a. The number of men involved in the given task.
b. The parts of the body which actually apply force--e.g., back, arms, etc.
c. The nature of the task required--e.g., lifting, carrying, etc.
d. The frequency with which the task must be accomplished.
e. The distance over which force must be exerted.
f. Equipment features which are available or must be supplied to facilitate the task--e.g., handles, carts, dollies, lifts, etc.

CAUTION: The design values provided in this section are based on the maximum force which can be exerted by the weakest 5 percent of the normal, American males, aged 18-30.

These design values should be reduced if:

a. The object is very difficult to handle--e.g., bulky, slippery, etc.
b. Access and work space is less than optimum.
c. The required force must be applied continuously for more than one minute.
d. The object must be finely positioned or delicately handled.
e. The task must be repeated frequently--e.g., many times on a given day.

These values may be slightly increased if:

a. A lifting yoke or other special harness will be used, etc.
b. The object is unusually easy to handle.
c. The required force must be applied infrequently and/or only for seconds.
d. The working body parts are provided suitable support.

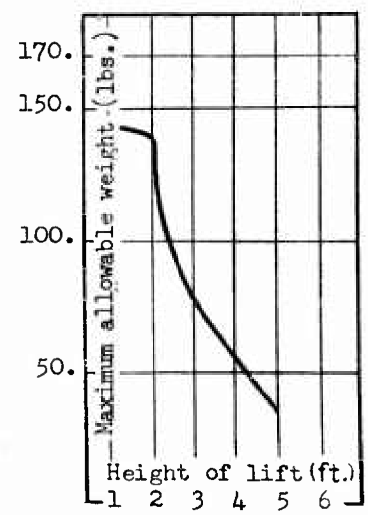
LIFTING CAPACITY:

General recommended weight limits:

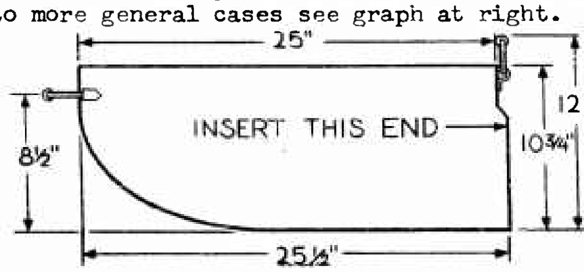
75 lbs for objects lifted infrequently and over short distance by one man.
40 lbs for objects lifted frequently or over moderate distance by one man.
14 lbs for portable equipment. (See p. 115)

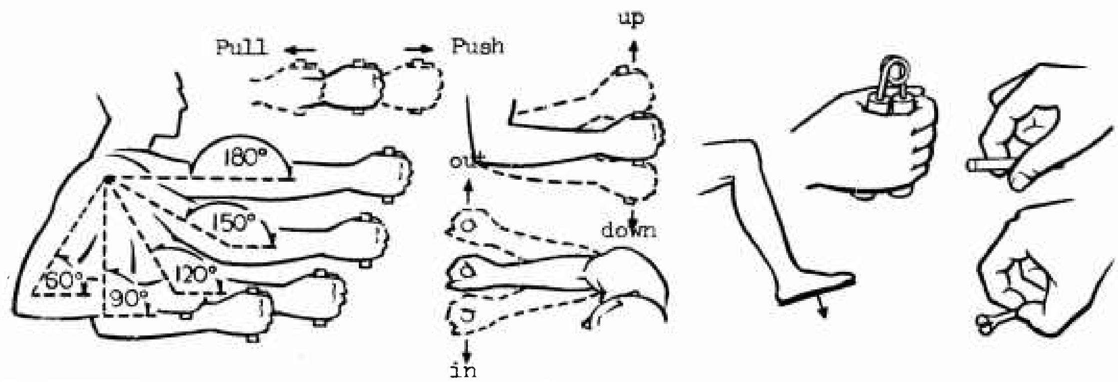
MAXIMUM LIFTING CAPACITY:

Weight of object (lbs)	Height of lift in feet* 1	2	3	4	5
Design values:	142	139	77	55	36
Distribution parameters:					
Mean:	231	193	199	81	58
S.D.:	47	40	31	19	16



* These data are based on experiments with the F-86H ammunition case pictured below. For extrapolation to more general cases see graph at right. (Ref. 15)





ARM STRENGTH:

Degree of Elbow Flexion		PULL R.	PULL L.	PUSH R.	PUSH L.	UP R.	UP L.	DOWN R.	DOWN L.	IN R.	IN L.	OUT R.	OUT L.
		Design Values (in lbs.) for Given Actions*											
180°		52	50	50	42	14	9	17	13	14	8	20	13
150°		56	42	42	30	18	15	20	18	15	8	20	15
120°		42	34	36	26	24	17	26	21	15	10	22	20
90°		37	32	36	22	20	17	26	21	16	10	18	16
60°		24	26	34	22	20	15	20	18	17	12	20	17
		Distribution Parameters											
180°	Mean:	121	117	138	126	43	41	41	35	35	30	50	43
	S.D.:	37	37	49	47	22	23	18	15	24	20	26	22
150°	Mean:	122	112	123	111	56	52	47	41	33	29	54	47
	S.D.:	36	37	45	48	28	27	18	16	18	20	25	27
120°	Mean:	104	94	104	99	60	54	58	51	35	30	53	40
	S.D.:	31	34	43	42	24	25	23	23	17	18	26	21
90°	Mean:	88	80	87	83	56	52	54	49	37	33	50	48
	S.D.:	30	28	33	35	22	22	20	20	18	19	23	22
60°	Mean:	63	64	92	80	49	44	51	46	42	32	52	50
	S.D.:	22	23		31	18	18	21	18	20	17	19	21

* The given values are the forces that 95% of the male population can exert.
For two-handed efforts add the appropriate values.
For two-man efforts double the appropriate values.
Data adapted from Ref. 29.

LEG, HAND AND THUMB FINGER STRENGTHS:

Appliable force (lbs.)	Leg (push)* R.	Leg (push)* L.	Hand Grip* R.	Hand Grip* L.	Thumb-Finger Grip (palmar)	Thumb-Finger Grip (Tips)
Design values (momentary):	413	387	63	65	15	12
Distribution parameters:						
Mean:	578	552	108	108		
S.D.:	100	100	21	18		
Design values (sustained):	200	200	42	38	15	12

* Values given assume optimum pedal position and hand holds.
Data adapted from Ref. 39.

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SUBJECT INDEX

* Major subsections of the Guide are shown in capital letters.

TIM CHART

MAJOR TOPIC AREAS	Accesses	Body Dimensions	Connectors	Covers, Cases & Shields	Disposable Modules	Drawers & Racks	Environment	Fasteners	Ground Support Equipment	Handles	Human Strength	Interchangeability	Lines & Cables	Mounting & Packaging	Personnel Fact	Pl
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Color									D 98				D 79			
Controls & Displays									C 95							D 10
Handling				C 82		I 51							D 78	I 60		C 10
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Materials				D 84				D 62					D 81			
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Shape	I 43			D 82						D 52		I 125				C 10
Size	C 44			D 82						C 53		I 125				C 10
Storage					D 124				D 96				D 78			I 101
Transportability									C 95	I 52						I 100
Type Preferences	C 42		C 72	C 85				D 64								
Weight				I 82						C	D 142			I 58		
Work Clearances	C 42		I 69	C 82		C 51		D 62						C 59		

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…, Cases & Shields

Disposable Modules	Drawers & Racks	Environment	Fasteners	Ground Support Equipment	Handles	Human Strength	Interchangeability	Lines & Cables	Mounting & Packaging	Personnel Factors	Platforms, Stands & Shelters	Stairs, Ladders & Ramps	Standardization	Test Equipment	Test & Service Points	Tools	Utilization	Work Space
		D 131						D 77							I 87			
						D 142												
	I 51						C 125	C 77	D 59				I 121	C 113	C 88	C 118	I 122	
	D 51												I 121	I 112	I 89			
124													I 121				C 123	
	51								D 55									
		125-133	I 62	C 94			D 125	I 77	D 54		C 100	I 104		D 109				C 47
	I 51		62-67				D 125	I 77			I 100		I 121			C 118	D 122	
		C 127		94-99							I 100							
	I 51				52-53				D 60		D 100			I 115				
I 124	I 51			C 94	C 52	142-143			D 60			D 104						
I 124				C 94			125		D 57				C 120	D 112				
	I 51			C 94			D 125	77-81	I 61				I 121		D 87	C 118	I 122	
		I 131	C 63				C 125	C 78	54-61				C 121	C 112		C 118	C 123	
						I 142			D 54	134				C 109	D 87	C 118		
											100-103							
											I 100	104-108						
C 124			C 62	C 94			C 125	D 77			D 101		120-121	C 110	C 87	I 118	C 122	
		I 127												109-117	C 87			
									C 54					C 112	87-93		C 122	
I 124			C 62						I 59							118-119		
C 124									I 54					I 112			122-123	
	C 51	D 131				C 142					C 100	C 104			I 87			47-50
	C 51				C 52			I 77	C 59						C 87		I 122	
			C 67	C 96				I 78	C 56		I 101							I 47
C 124			I 63	C 96				C 81	C 58		I 101		C 121	C 113	C 89			
				D 98				D 79							I 89			
				C 95							D 100			C 114				C 47
	I 51							D 78	I 60		C 100	D 105		C 115			I 123	
			D 63		C 53			C 77				C 104			I 88			
			D 62					D 81				I 105						
		D 131		C 99				C 81	C 60			C 105		C 112				C 47
					D 52		I 125				C 101	C						
					C 53		I 125				C 101	C						
D 124				D 96				D 78			I 101			C 115				
				C 95	I 52						I 100	I 105		C 109				
			D 64									C 104						
					C	D 142			I 58									
	C 51		D 62						C 59			I 104			C 87			C 47

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TIM CHART

LEGEND

Numbers refer to pages in the text where interactions occur.

Letters indicate the degree of criticality of the interaction.
- C - Critical
- I - Important
- D - Desirable

ASD TR 61-424

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This report presents recommendations and requirements for maintainability in Air Force weapon systems at the systems and detail design levels. Many of these recommendations and requirements are a result of analysis and integration of previously published data. Others stem from consultation with contractor and Using Command personnel as well as from the authors' own experiences. (over)

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